# A Shared Foundation: Advancing Remediation Innovation Through Policy and Technology

Prepared by Enviro Q&A Services

for

Alberta Chapter/Canadian Land Reclamation Association

and Alberta Innovates

April 2026

Enviro Q&A Services

## CITATION

This report may be cited as:

Powter, C.B., 2026. A Shared Foundation: Advancing Remediation Innovation Through Policy and Technology. Prepared by Enviro Q&A Services, Edmonton, Alberta for Alberta Chapter/Canadian Land Reclamation Association and Alberta Innovates. 91 pp.

## TABLE OF CONTENTS

## LIST OF FIGURES

## REPORT SUMMARY

Sixty people attended the March 2026 workshop, *A Shared Foundation: Advancing Remediation Innovation Through Policy and Technology*, sponsored by the Alberta Chapter, CLRA and Alberta Innovates. Participants held a variety of roles addressing contamination in multiple sectors with varying years of experience but were mostly project managers with 20+ years of experience working on upstream oil and gas sites.

The objectives of the Workshop were to:

1. Provide opportunity for discussions on current challenges and opportunities in the remediation space; and
2. Explore current and emerging innovations shaping remediation practices in Alberta.

A pre-workshop survey was conducted to set context for the Workshop discussions where the workshop participants addressed four topics:

1. Leveraging Innovation Throughout the Remediation Life Cycle;
2. Sampling and Analysis: The Remediation Backbone;
3. Opportunities for Increasing Technology-enabled Remediation; and
4. Opportunities to Improve Submission: From Problem to Solution

Key results from the pre-workshop survey were:

1. Salts and light- and heavy-end hydrocarbons were reported as the contaminants most frequently worked on, consistent with the emphasis on upstream oil and gas sites being the most frequently reported sector worked on. Salts were identified as the most difficult contaminant to address.
2. Surface soil and subsoil were identified as the media most frequently worked in, but bedrock was identified as the most difficult media to work in.
3. Modelling and treatment technologies were ranked the highest in terms of innovation needs.
4. Guidelines values and liability assessments were ranked highest in terms of regulatory innovation needs.
5. Cost to develop innovations and acceptance by government were identified as the biggest impediments to innovation.
6. Collaboration between regulators and practitioners and between industry and academia were ranked as having the highest ability to accelerate innovation.

By the end of the Workshop, there was a clear recognition that innovation in remediation is not only possible but imperative – if cost, regulatory, and cultural barriers are addressed. The discussion generated a rich inventory of promising technologies and improvement opportunities, summarized below, which can inform strategic initiatives going forward.

The main points arising from the four workshop sessions were:

1. **Leveraging Innovation**

   Leveraging innovation in remediation requires overcoming serious cost and culture hurdles, but it also demonstrated through real examples that new technologies – from bioremediation to AI – can deliver better, faster, cheaper results in certain contexts. The session concluded with a call to extract key lessons from these discussions and integrate them into the final workshop recommendations, ensuring that the ideas on innovation would be communicated to the full audience and decision-makers in a compelling way.

2. **Sampling and Analysis**

   Accurate, timely sampling and analysis are the bedrock of any successful remediation. The participants identified both high-tech and low-tech ways to strengthen this foundation: from adopting AI and field sensors, to improving training, to streamlining lab interactions. The insights from this session set the stage for incorporating technological advancements in the critical early phases of remediation projects, ensuring that subsequent decisions are based on solid data.

3. **Technology-enabled Remediation**

   The discussion was forward-looking, scanning the horizon for technological leaps and asking, "what will it take to get there?" It balanced excitement for new tools (AI, advanced treatments, big data, and automation) with a realistic appraisal of the structural changes needed (funding, policy tweaks, and culture shift). The discussions built upon earlier ones by fleshing out a roadmap of opportunities – giving the workshop concrete ideas to refine into recommendations for increasing the role of technology in remediation practice.

4. **Improving Submissions**

   Participants discussed tightening the "last mile" of remediation. They identified that the greatest technology or remediation effort can be undermined by poor documentation or procedural delays at the end. The opportunities and challenges discussed aimed at ensuring that cleanup efforts are effectively translated into regulatory approvals and site closures, which ultimately is the measure of success for any remediation project.

## ACKNOWLEDGEMENTS

The Alberta Chapter, Canadian Land Reclamation Association's Stewardship Committee provided funding for this project, and the Chapter and Alberta Innovates provided funding for the Workshop.

Whitecap Resources Inc. sponsored the workshop venue and meals.

The author and Committee wish to acknowledge the table moderators:

| | |
|---|---|
| Adam Dunn | Andrea Bullinger |
| Carlene Schmidt (Trace) | Diana Dun (CNRL) |
| Heather Jones (AER) | Jason Desilets (Cenovus) |
| Oscar Pula (Trium) | Ryan Puhlmann (GCL) |
| Shane Patterson (Alberta Innovates) | Tyrel Hemsley (EPA) |

Shane Patterson graciously volunteered to compile the workshop session notes from the Meet geek recordings and provide Meet geek training to the moderators.

Finally, the author and Committee are grateful to the Participants for sharing their knowledge, experience, and expertise.

## DISCLAIMER

Neither the Alberta Chapter/Canadian Land Reclamation Association nor Alberta Innovates endorses any technology or tool mentioned in this report.

Comments about organizations or agencies are those of the participants and are not the views of the Alberta Chapter/Canadian Land Reclamation Association or Alberta Innovates.

## GLOSSARY

**Tier 1 Guidelines**

Alberta Tier 1 Soil and Groundwater Remediation Guidelines (Alberta Environment and Protected Areas, 2024a).

**Tier 2 Guidelines**

Alberta Tier 2 Soil and Groundwater Remediation Guidelines (Alberta Environment and Protected Areas, 2024b).

## ACRONYMS

| | |
|---|---|
| AER | Alberta Energy Regulator |
| AI | Artificial Intelligence |
| APEC | Areas of Potential Environmental Concern |
| ASTM | American Society for Testing and Materials (now ASTM International) |
| CSM | Conceptual Site Model |
| EPA | Alberta Environment and Protected Areas |
| GC/MS | Gas Chromatography / Mass Spectrometry |
| GIS | Geographic Information Systems |
| IoT | Internet of Things |
| ISM | Integrated Sampling Methods |
| ITRC | Interstate Technology & Regulatory Council |
| LiDAR | Light Detection and Ranging |
| NGIF | Natural Gas Innovation Fund |
| NIR | Near Infrared |
| PDF | Portable Document Format |
| PFAS | per- and polyfluoroalkyl substances |
| PFOS | perfluorooctane sulfonate |
| PTAC | Petroleum Technology Alliance Canada |
| QA/QC | Quality Assurance / Quality Control |
| SR&ED | Scientific Research and Experimental Development |
| VR | Virtual Reality |

| | |
|---|---|
| XRF | X-ray Fluorescence |

# 1 INTRODUCTION

Participants in the 2024 Alberta Chapter/Canadian Land Reclamation Association Workshop *Towards a Shared Foundation for Innovation and Evolution* (Powter, 2024) noted that "reclamation and remediation are inextricably linked, so holding a preliminary workshop like this one to scope out remediation issues for future discussions would be beneficial." To that end the Chapter organized this follow-up Workshop to discuss remediation.

A Workshop Planning Committee developed the Workshop agenda, session topics and questions, and the pre-workshop survey:

| | |
|---|---|
| Adam Mathison, Northshore Environmental | Ben Pratt, Millennium Environmental Management Systems |
| Corey Zadko, Alberta Energy Regulator | Diana Dunn, AC/CLRA Stewardship Committee |
| James Agate, Canadian Natural Resources Limited | Jason Desilets, Cenovus |
| Kim Cleland, Earthmaster Environmental | Oscar Pula, Trium Inc. |
| Shane Patterson, Alberta Innovates | Simone Levy, Waterline Resources |
| Tyrel Hemsley, Alberta Environment and Protected Areas | |

## 1.1 Workshop Objectives

The objectives of the Workshop were to:

1. Provide opportunity for discussions on current challenges and opportunities in the remediation space; and
2. Explore current and emerging innovations shaping remediation practices in Alberta.

## 1.2 Pre-Workshop Survey

The Workshop Planning Committee designed a pre-workshop survey to gather background information about the common types of contaminants, industrial sectors, and environmental settings practitioners worked in and where they saw the greatest innovation needs. The survey was broadly distributed on January 5, 2026, through the CLRA, Environmental Services Association of Alberta, and LinkedIn. The survey closed February 20, 2026.

## 1.3 Workshop Format

Workshop participants were asked to address four topics:

1. Leveraging Innovation Throughout the Remediation Life Cycle;

2. Sampling and Analysis: The Remediation Backbone;
3. Opportunities for Increasing Technology-enabled Remediation; and
4. Opportunities to Improve Submission: From Problem to Solution

Participants were allocated in advance to 10 discussion tables, and table participants were changed for each discussion topic to provide an opportunity to hear different perspectives. Each table was provided a series of questions to help focus discussions (APPENDIX 2), but participants were free to talk about other points as well.

### 1.4 Workshop Participants

The AC/CLRA posted a notice on its website on December 22, 2025, requesting practitioners to submit an Expression of Interest (EOI) in attending the workshop, with a closing date of January 26, 2026. Ninety-one people submitted EOIs and 60 registered for the Workshop (APPENDIX 3).

### 1.5 Workshop Moderators

The Committee asked 10 participants to be table moderators. Moderators were to ensure the discussions remained focused on the topic and to actively encourage all participants to engage in the discussions. They were also allowed to contribute to the discussions. The moderators were:

| | |
|---|---|
| Adam Dunn | |
| Andrea Bullinger | Ram River Environmental Consultants |
| Carlene Schmidt | Trace Associates |
| Diana Dunn | Canadian Natural Resources Limited |
| Heather Jones | Alberta Energy Regulator |
| Jason Desilets | Cenovus Energy |
| Oscar Pula | Trium Environmental Inc. |
| Ryan Puhlmann | GCL Environmental Ltd. |
| Shane Patterson | Alberta Innovates |
| Tyrel Hemsley | Alberta Environment and Protected Areas |

### 1.6 Digital Note Takers and AI Summaries

The Committee adopted the use of Microsoft CoPilot (AI) to summarize and collate the information collected from the MeetGeek (AI) software that recorded table discussions, after its successful use in the 2025 Chapter Workshop (Richens and Patterson, 2025).

APPENDIX 5 provides a description of the MeetGeek and Microsoft CoPilot procedures used to develop the Workshop summaries in sections 4 to 9.

APPENDIX 6 provides some additional insights gained from focused Microsoft CoPilot queries on:

- Professional Responsibility, Accountability and Liability
- Policy and Legislation
- Standards and Guidelines
- Costs and Economics
- Education and Training Needs and Opportunities

### 1.7 Report Structure

Section 2 provides the results of the pre-workshop survey. Section 3 provides information on the workshop participants. Sections 4 to 7 provide summaries of the four discussion topics generated by Microsoft CoPilot. Section 8 provides common themes arising from the discussions and recommended next steps.

## 2 PRE-WORKSHOP SURVEY

The goal of the pre-workshop survey was to gather background information on the types of remediation issues practitioners face, what they consider to be the biggest challenges, and where innovation in the remediation space is required. The results of the survey were presented at the workshop as context for the discussions.

### 2.1 Respondent Background

A total of 79 people completed the survey. Another 25 people answered some of the first eight questions then quit. Their responses are included in the Figures and n= numbers below.

Most respondents were Project Managers (Figure 1), and most work in Upstream and Midstream Oil and Gas (Figure 2).

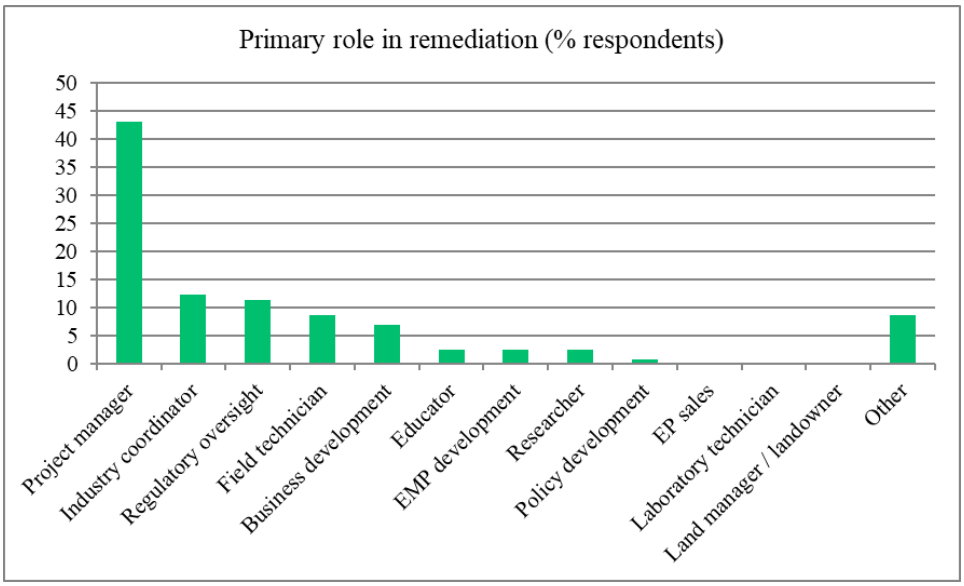


Figure 1. Primary role in remediation.
n=114
EP = Equipment/product sales; EMP = Equipment/method/process development

Participants selecting Other listed[1]:

- Portfolio manager (50+ projects) / technical accountable (soil impacts, minor groundwater quality concerns)
- Consultant and technical lead (subject matter expert) for the management of contaminated sites
- Soil science and remediation expert

[1] The survey design treated Other as a separate category such that a respondent could select one of the listed options AND Other to provide more context.

- Senior environmental scientist (I review data to determine if the site meets guidelines for remedial closure)
- Senior reviewer
- Manager and technical lead
- Technical advisor
- Training coordinator
- Technology and innovator
- Business owner for remediation technology
- Innovator
- Professor

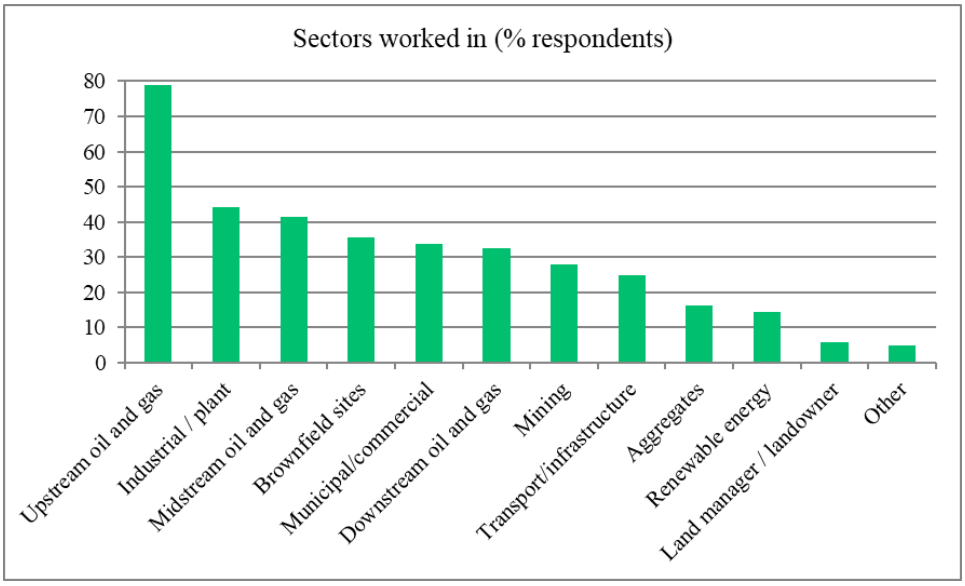


Figure 2. Sectors worked in.
n=109
Participants could select more than one sector. The 109 respondents identified a combined total of 375 sectors worked in.

Participants selecting Other listed[2]:

- First Nations
- University and Research Projects

[2] The survey design treated Other as a separate category such that a respondent could select one of the listed options AND Other to provide more context.

- Utilities, powerlines, substations
- Minor experience in mining at start of my career
- Environment and Protected Areas regulates all unauthorized releases except those that fall within the AER's mandate

Most respondents have worked in the remediation field for 20 years or more (Figure 3), and 77% of the 104 respondents indicated they also worked on reclamation.

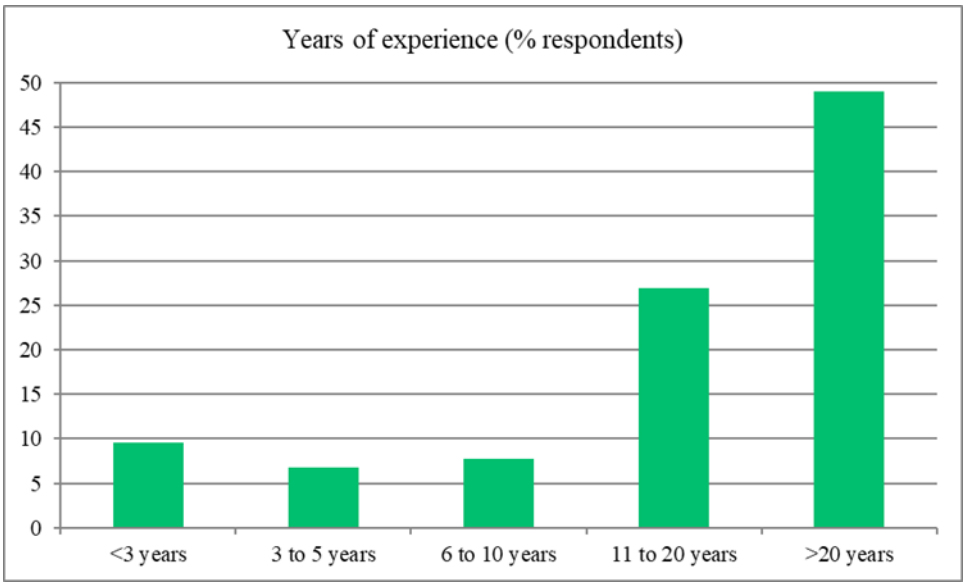


Figure 3. Years of respondent experience.
n=104

In the following sections, “work on” or “work in” includes any of the following activities related to remediation: field work, lab work, research, teaching, receiving and reviewing applications, setting or revising policy and legislation, conducting inspections/investigations, and developing and testing technologies, methods, processes, and tools.

## 2.2 Contaminant Types

Respondents work on a wide variety of contaminant types (Figure 4), with salts and hydrocarbons reported most frequently.

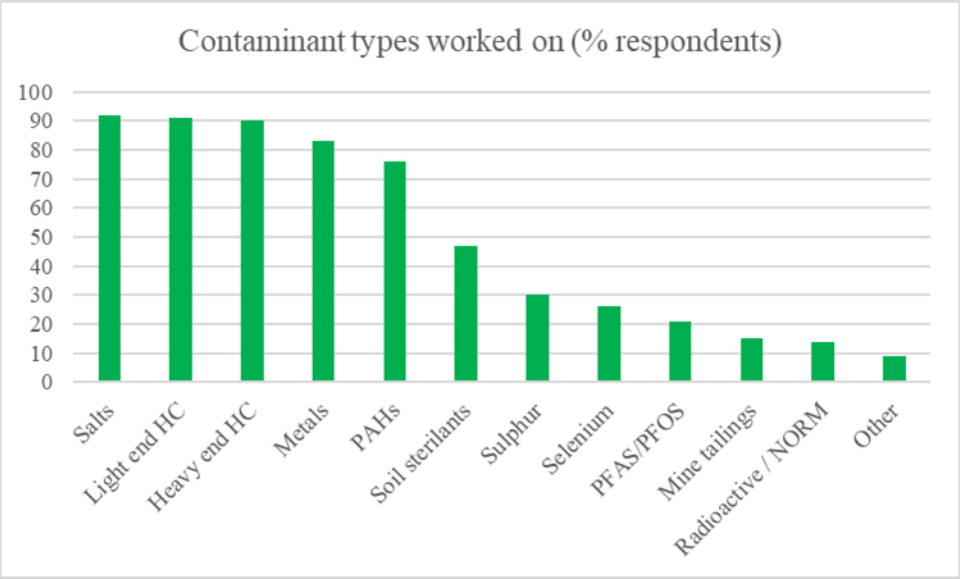


Figure 4. Contaminant types worked on by respondents.
n=110
Participants could select more than one contaminant type. The 110 respondents identified a combined total of 594 contaminant types worked on.

Participants selecting Other listed:

- Sulfolane
- coal flyash
- pH (acidic or basic soils in comparison to controls)
- Dioxins/furans
- Glycol
- Methanol
- Sulfinol
- Acid rock drainage
- Pesticides
- We provide regulatory direction on all types of releases, but have limited involvement with radioactive materials

Respondents identified salts as the most difficult contaminant types to work on (Figure 5).

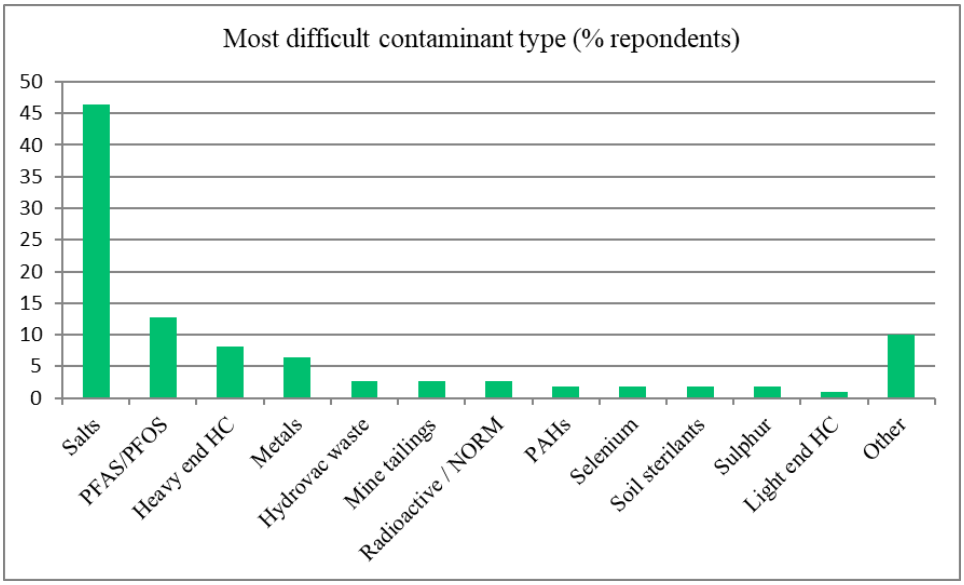


Figure 5. Most difficult contaminant types to work on.
n=110

Participants selecting Other listed:

- Depends on the site, setting, life cycle stage – they can all have challenges
- Depends on the site location, contamination depth, pathways and receptors
- It really depends on the nature of native materials at the site and what exposure pathways are active/operational at the site; I indicated salts because we have modelling tools (SST) to support closure, but really it could be any of these depending on the site
- All can have unique challenges (e.g., very deep chloride impacts within a Domestic Use Aquifer)
- PHC F2 is the most common contaminant that is challenging to manage due to very low guideline
- Sulphur is extremely challenging as well
- I'm very interested around policy updates for sulphur
- Soil sterilants are not common but can be hard to manage
- Solvents (e.g., TCE, PCE)
- Salts in an urban environment
- Chloride presents some current regulatory hurdles and hoops to close off
- pH

## 2.3 Environmental Media

Remediation is conducted on a variety of environmental media, with subsoil and surface soil being the most frequently identified by respondents (Figure 6). There may be a connection between the selection of soil and the 77% of respondents also working in reclamation, or it may be that soil contamination is most frequently found and assessed.

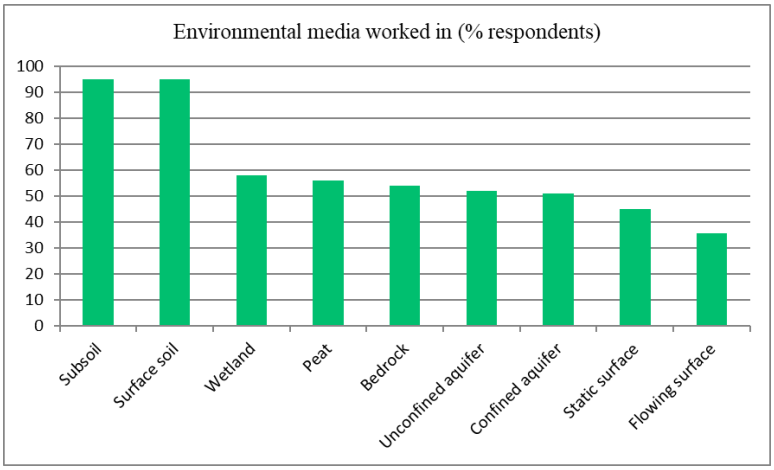


Figure 6. Environmental media in which remediation work occurs.
n=98
Participants could select more than one environmental media. The 98 respondents identified a combined total of 531 sectors worked in.

Respondents indicated that bedrock and wetlands were the most difficult media to work with (Figure 7).

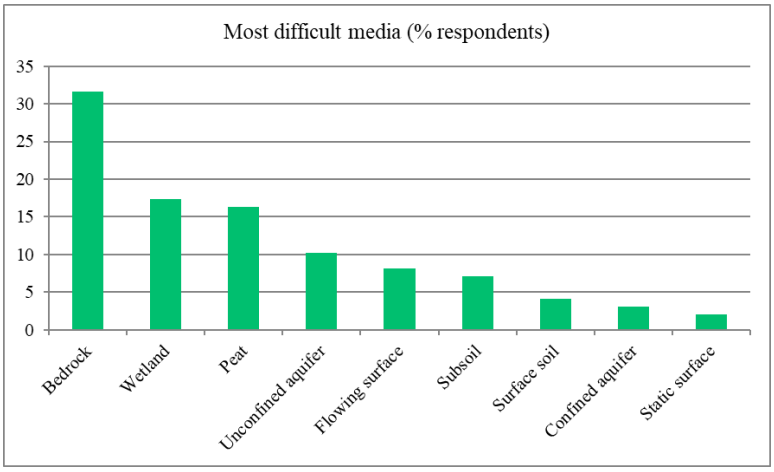


Figure 7. Most difficult environmental media to conduct remediation in.
n=98

## 2.4 Innovation

For the next four questions, respondents were asked to rank a list of possible responses from most important to least important.

Modelling and treatment technologies were identified as the stages of remediation requiring the most innovation (Figure 8). Interestingly, issues related to laboratory work were front and centre in the Workshop discussions, contrary to them being identified as the lowest ranked innovation need.

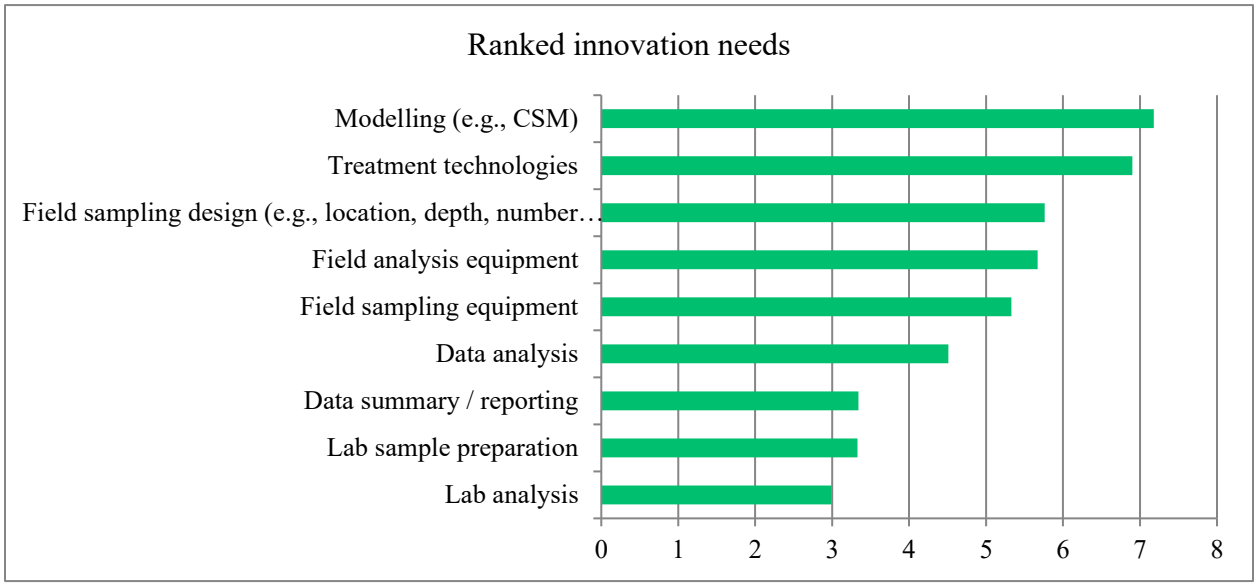


Figure 8. Remediation stage requiring the most innovation.
n=79

Guidelines values and liability assessments[3] for sites with contamination were the most frequently mentioned regulatory areas requiring innovation (Figure 9). Except for post-remediation auditing, all the priorities were discussed in the Workshop.

[3] See https://www.aer.ca/regulations-and-compliance-enforcement/liability-management-programs

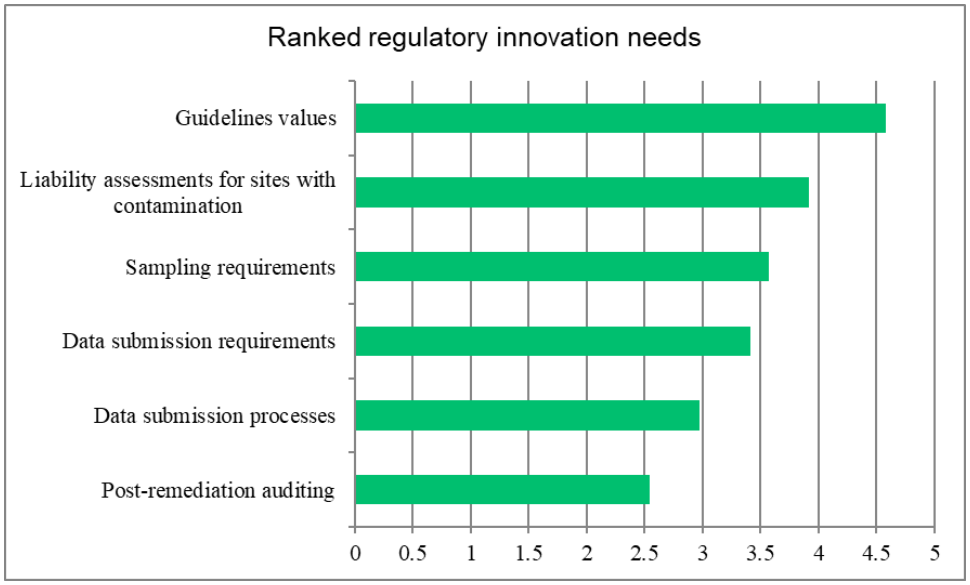


Figure 9. Regulatory area requiring the most innovation.
n=79.

Cost to develop innovations and acceptance by government/regulator were the most frequently cited impediments to remediation innovation (Figure 10). All the priorities were discussed in the Workshop though acceptance by government/regulator seemed to be more important than the survey suggests.

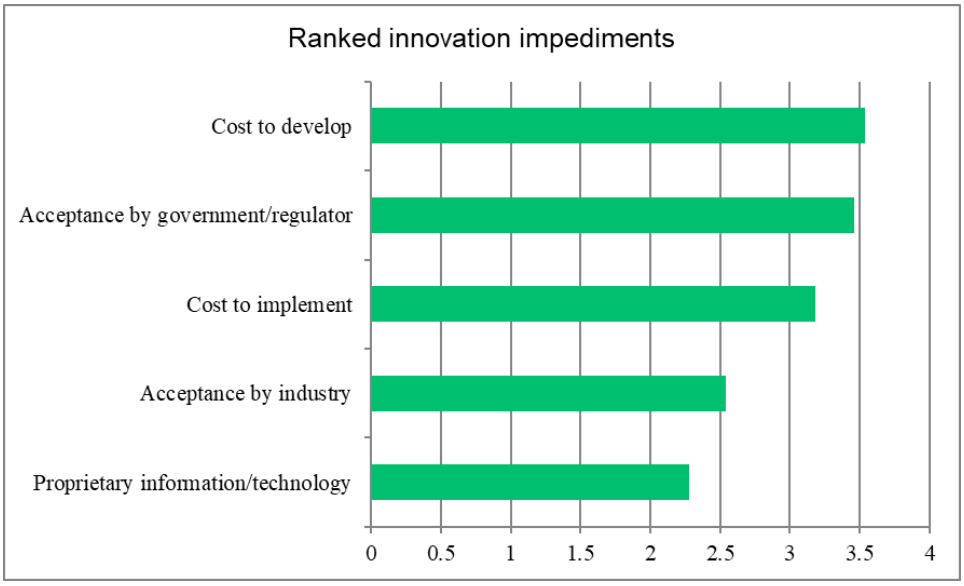


Figure 10. Impediments to remediation innovation.
n=79

Respondents were asked if there were other impediments to remediation innovation, and replied:

- Cost to industry to remediate and general limitations of financial ARO reporting (ARO reporting does not provide a plain language accounting of ARO liabilities to shareholders)
- The budgeting cycle of oil and gas for multiyear remediation approaches
- Budget cycles and certainty also play in
- The apparent lack of focus on remediation when the site has finished production and the earnings have ceased
- Long-term liability
- Only approach that quickly removes a liability is dig and dump when possible; sometimes the only one people believe in because they can see it
- Cheap landfill rates (in comparison to other parts of the world)
- Final result has to have closure certainty
- Need regulator buy-in of remedial objectives prior to conducting remediation
- Wider adoption and acceptance of Risk Assessment as an alternative to meeting generic guidelines
- A general lack of processes and risk management approaches, for certain types of impact (e.g., salt impacts in a slough)
- I feel like acceptance by government/regulator is a separate category that could be unpacked separately from decision making that companies must do internally to advance remedial actions; it would be helpful to me to understand regulatory delays more broadly
- Lack of timeline regulations/enforcement for remediation
- Residual chlorides following removal of EC and SAR impacted “hot spots” – Saskatchewan method of ongoing monitoring should be considered in Alberta
- Ability to use residual “remediated” / “treated” materials
- Remediation success
- Lack of treatability of most contaminants
- Alternative approach measurement often not integrated into pre-defined processes
- Multiple contaminants of concern – each may need a different approach
- Acceptance by other external stakeholders (e.g., landowners)
- Stakeholder (i.e., landowner, Public Land Managers) acceptance
- Business promoting remediation technologies without adequate science to prove that the remediation technology is effective (especially for Canadian climates)
- The lack of research with associated costs to develop remediation innovation

- Laboratory results when the site is in a remote location
- Lack of resources such as contractor/heavy equipment availability/GIS services
- Alberta climate provides limited opportunities
- Data sharing / data management

Respondents most frequently identified cooperative mechanisms like working groups and partnerships as an option to accelerate remediation innovation (Figure 11). Workshop discussions were consistent with the ranked priorities in the survey though the latter two choices were not mentioned.

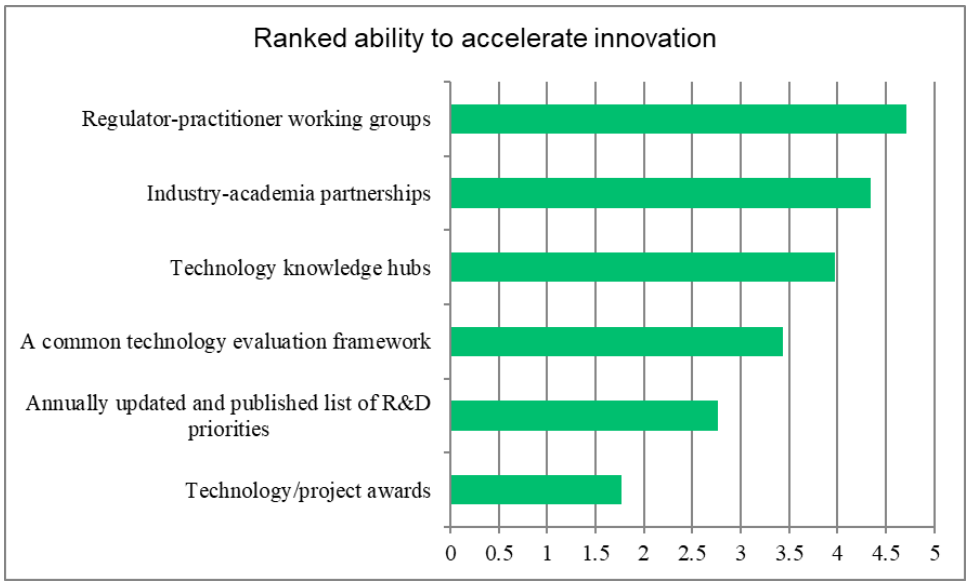


Figure 11. Options to accelerate remediation innovation.
n=79

Respondents were asked if there were other options for accelerating remediation innovation, and replied:

- Incentivizing innovation by (for example) providing financial incentives and regulatory support for development and deployment of new/innovative technologies
- Regulatory bodies must be empowered to accept non-traditional methods of closure and industry must be incentivized (both financially and with increased likelihood of success) to pursue closure innovations
- Regulator integration pathways
- Interest in remediation innovation is limited because the likelihood of success is deemed to be low
- Increasing landfill fees to make dig and dump less desirable

- Integrating a closed loop or circular system / approach that includes recycle and repurpose of waste materials (e.g., use impacted in construction) to reduce the overall environmental footprint and increase project efficiency
- Ensuring the whole lifecycle is looked at, and supported, not just focusing on a small aspect and trying to make data fit the outcome desired
- Investing in new research and technology
- Industry-Academia-Regulator-Practitioner groups with industry and government funding
- There seems to be lack of coordination in developing and sharing remediation innovation among industry sectors and between industries
- Pilot projects at meso-scale or full-scale
- Sharing successes or failures

### 2.5 Additional Comments

Respondents also provided additional comments:

- There are many examples of innovative remediation in Europe, where regulators and the public have no choice but to develop on lands impacted by historical operations. An example of this that may be useful in Alberta is the application of exposure control for site (especially remote sites). This option is largely overlooked as an opportunity in Alberta because leaving impacts in place will not receive regulatory approval and the licensees are unable to release specified land unless the site meets equivalent land capability (RFG[4] is an exception to that). Our regulations (and public perception) limit remedial innovation.
- Other jurisdictions such as Europe commonly rely on the principles of site-specific risk assessments for managing contaminated sites because they lack the extensive landfill capacity available in Alberta. To stay aligned with modern, sustainability-focused regulatory practices, Alberta's framework would benefit from more explicit integration of net environmental benefit, broader sustainability considerations, and more flexible risk assessment approaches.
- Regulations are too restrictive. Overall review with perspective of reasonable reclamation regulations and accepting techniques that help lower overall cost.
- Excavation and disposal is still a comparably less expensive remediation approach used all too often because practitioners are not knowledgeable enough about alternatives to Tier 2 closure
- Show the work and support it with corroborating evidence
- Politics and the "we have always done it this way" mentality is what kills the remediation innovation

[4] The author was unable to determine what this acronym means.

## 3 WORKSHOP PARTICIPANTS

A total of 60 people attended the workshop. About 34% of the participants were project managers (Figure 12) and the majority worked in upstream oil and gas (Figure 13).

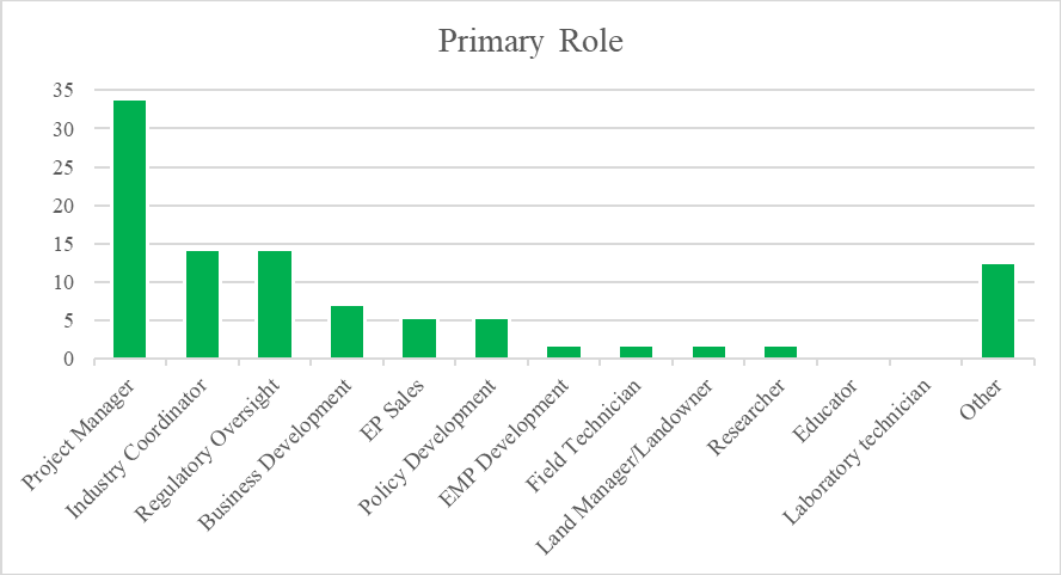


Figure 12. Workshop participant roles.
n=56.

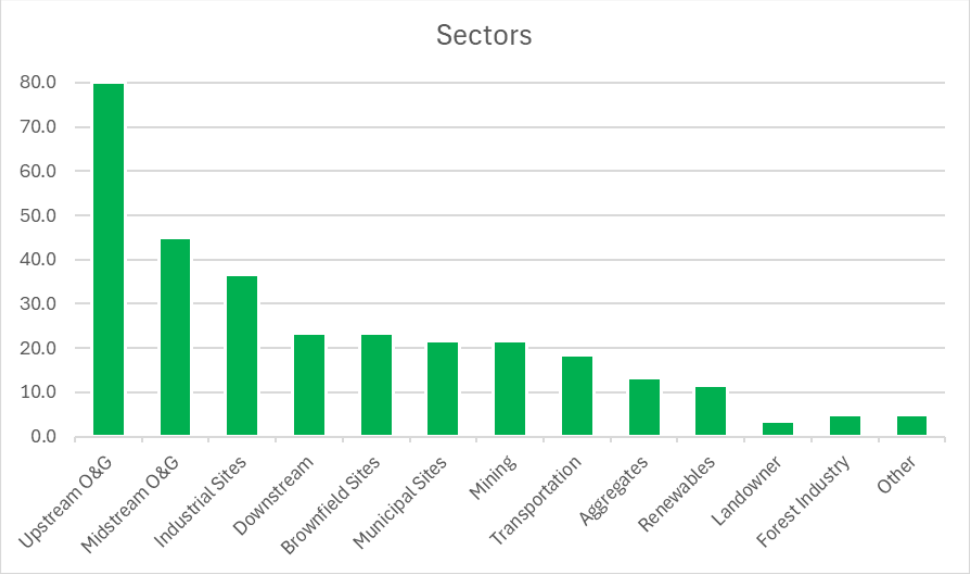


Figure 13. Workshop participant sectors.
Participants could select more than one sector. The 58 respondents identified a combined total of 185 sectors they work in.

Figure 14 shows that participants brought considerable experience to the table, with 77% of them having been involved for more than 11 years.

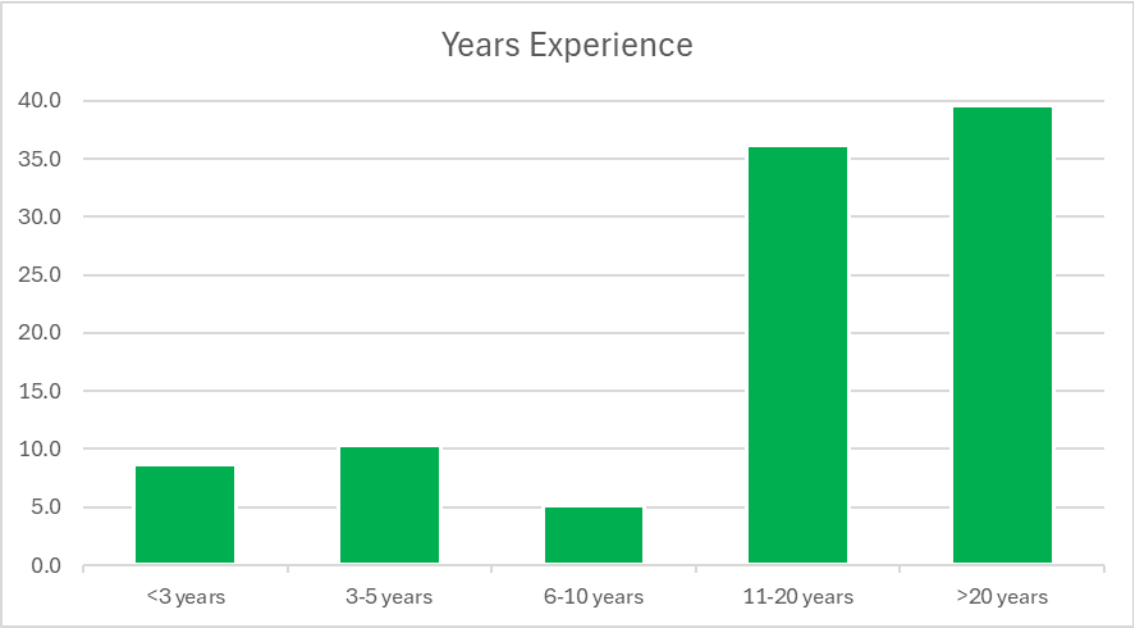


Figure 14. Workshop participant years of experience.
n=58.

The workshop survey results mirrored those of the broader survey reported in section 2.

# 4 WORKSHOP SUMMARY

This section contains the Microsoft CoPilot summary of the transcripts.

The Remediation Workshop discussion convened a diverse group of industry experts, regulators, consultants, and researchers to explore strategies for accelerating environmental remediation through innovation. Spanning four themed sessions, the workshop addressed the entire remediation lifecycle – from leveraging new technologies and methods in cleanup, to improving field sampling and analysis, expanding the use of automation and AI, and enhancing regulatory submission processes. A unifying theme was the urgent need to reduce reliance on traditional "dig-and-dump" landfill disposal in favour of advanced treatment and risk-based approaches, given escalating waste volumes and sustainability goals.

Barriers to adopting innovative remediation technologies were frankly discussed. Key challenges identified included the cost advantage of landfilling (which often remains cheaper than novel treatments), short project budget cycles and liability transfer incentives that discourage long-term experimentation, and regulatory risk aversion – agencies being cautious to approve unproven methods without extensive validation.

Limited sharing of data and proprietary approaches was cited as a hurdle to industry-wide learning, as was the lack of large, high-quality datasets that advanced analytics and AI could leverage. Data quality issues (like legacy reports locked in PDFs without geospatial context) and data security concerns also impede digital transformation. Moreover, the loss of experienced field personnel and mentorship due to retirements and increased automation has led to skill gaps that must be addressed to maintain on-site insight and quality control.

Despite these challenges, the workshop highlighted many opportunities and emerging technologies poised to revolutionize remediation. Participants emphasized the potential of artificial intelligence (AI) and machine learning across the project lifecycle – from rapidly generating conceptual site models (CSMs) and parsing decades of reports, to optimizing sampling plans and balancing remediation alternatives. Field teams are beginning to use AI-powered screening devices like "Trium"[5] that provide real-time soil contamination readings, accelerating delineation of spills and reducing laboratory turnaround times. Autonomous sensors and drones equipped with imaging (e.g., near-infrared) enabling remote monitoring of site conditions and large-area surveys. Other innovative technologies discussed included generative AI for 3D CSMs and report graphics, mobile field labs and portable analytical kits to get faster on-site data, and advanced in-situ methods like soil washing, electrokinetic treatment, and phytoremediation (using plants/microbes) to treat contamination on site. These tools, coupled

[5] See Trium's AISCT® (Artificial Intelligence Assisted Site Characterization Technology) – https://www.triuminc.com/#AISCT

with better digital data management, offer the promise of more efficient, sustainable remediation that can be tailored to site-specific risks rather than defaulting to excavation.

Collaboration and structured follow-up are needed to turn ideas into action.

Participants called for industry-led pilot programs and validation studies (potentially co-funded by operators, regulators, and research institutions) to de-risk new technologies and produce the evidence needed for broader acceptance. Regulators were encouraged to engage early by clarifying data requirements and success criteria for innovative methods, and to consider policy adjustments (e.g., updated guidelines or incentives) to support risk-based closures when cleanups achieve "good enough" outcomes for low-risk cases. The value of data sharing and standardization was repeatedly noted – e.g., using centralized databases like OneStop to make anonymized background data available, adopting electronic data deliverables instead of PDF reports to enable automated analysis, and developing common standards for digital submissions. By improving communication (through concise executive summaries, visual aids, and multi-line evidence of risk reduction) and by involving all stakeholders (consultants, operators, regulators, technology experts, and Indigenous/community voices) throughout the process, the sector can build confidence in new approaches.

Overall, the multi-session workshop allowed for sharing knowledge, showcasing emerging solutions, and building consensus on next steps. Each session blended practical case studies with forward-looking ideas, maintaining strong engagement from participants. By the end, there was a clear recognition that innovation in remediation is not only possible but imperative – if cost, regulatory, and cultural barriers are addressed. The discussion generated a rich inventory of promising technologies and improvement opportunities, summarized below, which can inform strategic initiatives going forward.

Appendix 4.2 to Appendix 4.4 provide tabular summaries of the sections below.

### 4.1 Opportunities

***Industry-led Pilots and Validation Programs***: There is an opportunity for industry consortia and funding bodies to collaboratively pilot innovative remediation technologies at scale. By pooling resources and expertise to conduct field demonstrations under real-world conditions (and openly publishing the results), the sector can de-risk new methods and generate the evidence needed for regulatory acceptance. Accelerator programs or challenge grants could spur these pilot projects.

***Regulator-Industry Engagement to Update Policies***: Participants saw promise in more proactive engagement with regulators to modernize guidelines and approval processes. For example, policy teams could use data from pilot studies to adjust overly conservative cleanup criteria or to incorporate risk-based Tier 2 approaches for low-risk scenarios. In the near term, setting up regular forums or working groups with regulators (possibly under professional associations) was

viewed to build trust and ensure regulators' concerns are addressed early in technology development.

A clear opportunity is to leverage existing platforms (like Alberta's OneStop database or other regional environmental data systems) to share non-proprietary site data and background values among stakeholders. By aggregating historical remediation data, practitioners can better establish realistic background levels and successful case studies, while AI tools get more "fuel" for learning.

***Data Sharing and Centralized Repositories***: Stakeholders recommended creating shared portals or data trusts for soil and groundwater datasets, once privacy and liability issues are worked out.

***Adopting Electronic Reporting Standards***: Converting the regulatory submission process from static PDF reports to standardized electronic data files is a low-hanging opportunity to improve efficiency. If companies submit structured data (spreadsheets, GIS layers, etc.), regulators can automate parts of the review and easily mine the data for insights. This also opens the door for machine learning algorithms to identify trends across sites. Workshop members suggested that moving to electronic data deliverables and requiring consistent data fields would be a gamechanger for transparency and analysis.

***Real-time Field Analytics and Decision-making***: The group identified significant opportunity in deploying more real-time analytical tools on site. Using portable GC/MS devices, immunoassay kits, or AI-driven field scanners can allow remediation teams to make immediate decisions – such as stopping excavation when cleanup goals are met or redirecting drilling locations on the fly. Expanding the use of these tools, coupled with robust correlation to lab results, could greatly reduce delays and costs. A next step is to design projects that integrate field analytics into the workflow and document how they cut down iterative mobilizations.

Enhancing natural attenuation and phytoremediation is an underutilized opportunity. Aligning such approaches with risk-based closure (accepting residual contamination if risk is mitigated by natural processes) was seen as a path forward.

***Bioremediation and Nature-Based Solutions***: Trials with certain plants, fungi, and soil amendments have shown impressive results in degrading contaminants on site. The opportunity is to apply these nature-based solutions more broadly – for instance, using fast-growing, hydrocarbon-tolerant plants (willows, hemp) or stimulating native microbes – especially in remote areas or large plumes where excavation is impractical.

***Integrated Sampling and Advanced Characterization***: Another opportunity lies in refining how sites are characterized through integrated sampling methodologies (ISM) and high-resolution

tools. By adopting ISM (combining many soil increments for a representative sample) and using direct-push sensors or improved analytical techniques, practitioners can obtain more accurate pictures of contamination extent. This reduces the chance of missing hotspots and can optimize remedial designs. Several participants suggested developing standard protocols for integrated sampling and pushing regulators to accept these techniques as part of closure evidence, which could improve outcomes and reduce rework.

***Leveraging AI for Historical Data and Trend Analysis***: The wealth of existing environmental data offers an opportunity for AI-driven analysis to extract lessons. Participants proposed using AI to quickly summarize decades of reports, interpret monitoring trends, and even flag likely areas of concern at complex sites. In one example, an AI was used to plot thousands of data points in 3D, revealing patterns that informed a targeted remedial strategy. By scaling up these efforts – possibly through cloud computing resources – companies can identify which approaches worked best in which contexts, providing a data-driven basis for future project planning.

***Workforce Development and Knowledge Transfer***: The human capital aspect was seen as an opportunity as well: investing in training programs, workshops, and perhaps virtual reality (VR)-based learning to rapidly upskill new environmental professionals. As senior experts retire, capturing their knowledge (for example, through mentorship pairings or even recording their decision-making via AI "copilots") could prevent loss of institutional memory. Some attendees suggested cross-organizational knowledge exchanges and publishing "what went wrong" case studies, so the broader community can learn from each other's mistakes and innovations rather than reinventing the wheel.

> One heavy equipment company participant felt that he couldn't contribute much to a workshop dominated by 15+ year professionals and consultants, and yet we rely on their expertise as much as those of the "professionals" to be successful. Perhaps a hands-on demonstration and discussion Showcase Committee tour is a solution to better engaging this important part of our community.

***Cross-sector Collaboration and Standards***: Finally, there is a strong opportunity for multi-stakeholder collaboration to set the groundwork for innovation. This includes developing standardized protocols and guidance for new technologies (potentially through groups like ITRC[6], ASTM, or national forums). By involving regulators, academia, technology vendors, and practitioners in creating these standards, new methods can be codified more quickly. An example raised was creating a shared "technology clearinghouse" of validated remediation case

[6] See https://itrcweb.org/

studies and perhaps a certification program for tools that meet certain performance criteria. Such collaborative frameworks would streamline adoption of emerging solutions across the industry.

### 4.2 Challenges

***Cost and Budget Pressures***: A fundamental challenge discussed is that innovative remediation options often struggle to compete on cost with the status quo. Landfilling contaminated soil remains relatively cheap and reliable, making it hard for newer, in-situ technologies (which may have higher upfront costs or longer timeframes) to gain traction. Short project timelines and annual budget cycles also mean companies tend to favour solutions that show immediate results within the fiscal year, rather than longer-term investments like multi-year bioremediation or monitoring programs.

***Regulatory Risk Aversion***: Regulators were seen as cautious to approve or credit novel approaches without extensive proof. This conservative stance – while rooted in ensuring protection – poses a hurdle for innovation. Companies fear spending money on an unproven technique only to have regulators reject the outcome. The workshop noted instances of regulators requiring confirmatory lab data even when field measurements were promising or hesitating to accept modelling results without traditional sampling densities. Overcoming this will require building regulators' confidence through pilots and clear demonstration of equivalence to current methods.

> The poor availability and quality of data was universally seen as a challenge. Without clean, comprehensive datasets, powerful analytics and AI cannot be fully leveraged, making it challenging to identify trends or verify new techniques at scale.

***Data Silos and Quality Issues***: Many companies maintain large troves of environmental data that are not readily usable – they exist in disparate formats, lack geolocation, or contain gaps and errors. Legacy reports often have important information locked in scanned documents, thwarting efforts to automate data analysis

***Proprietary Mindset and Lack of Sharing***: An industry cultural challenge identified is the reluctance to share data and lessons learned. Because environmental data can be tied to liability or competitive advantage, organizations are often hesitant to publish results (especially failures). This means each company might be duplicating experiments or not learning from others' mistakes. The workshop noted that an unwillingness to share successful remediation "recipes" or regional background data hampers collective progress. Legal and reputational concerns (e.g., admitting a problem) further complicate open collaboration.

***Workforce and Experience Gaps***: The decline in experienced field personnel was raised as a serious challenge. Younger staff may lack mentorship in fundamental skills like soil logging, sampling protocols, or intuitive decision-making in the field. Mistakes such as mis-handled

samples, poorly executed well installs, or overreliance on software outputs can result. Additionally, the industry's heavy workload and remote work trends (exacerbated by the pandemic) have reduced on-the-job training opportunities. If not addressed, this loss of institutional knowledge could lead to lower quality remediation outcomes and a resistance to adopting complex new methods that require specialist expertise.

***Fragmented Jurisdictional Requirements***: Remediation practitioners operate under a patchwork of regulations that vary by region. The workshop highlighted that inconsistent rules and interpretations between jurisdictions (e.g., between different provinces or states) complicate the implementation of new approaches. For instance, some areas have prescriptive sampling and screening requirements, whereas others allow more professional judgment. These differences pose a challenge for companies working in multiple regions, as an approach accepted in one place might not be allowed in another. Harmonizing standards or achieving mutual recognition of innovative methods is a long-term challenge noted by participants.

***Long Review Times and Uncertain Approval***: A practical challenge is that even when companies try something innovative, regulatory review and approval can be protracted. Attendees mentioned long turnaround times for complex site closure submissions and instances where minor issues lead to significant delays or requests for more data. This uncertainty in outcome and schedule makes project managers risk-averse about deviating from conventional approaches. Improving the efficiency and clarity of the review process (perhaps via better submission guidelines or more regulator resources) was deemed necessary to mitigate this challenge.

***Technical Limitations of New Tools***: Several innovative technologies come with their own challenges that must be tackled. For example, field sensor tools can suffer from interferences or detection limits (e.g., chloride test kits being confounded by high sulphate or clay content) leading to inaccurate readings. AI models can generate plausible-looking but incorrect results if trained on poor data – a phenomenon referred to as AI "hallucinations". Additionally, many new remediation methods (like certain in-situ treatments) have niche applicability or unresolved issues, meaning they are not one-size-fits-all solutions. Recognizing and openly discussing these technical limitations is a challenge that must be met to refine the technologies.

Protecting sensitive site data (which could include proprietary information) is paramount, and fear of hacks or data misuse might make companies hesitant to adopt connected technologies.

***Cybersecurity and Data Privacy Concerns***: As the industry becomes more digitized (IoT sensors, cloud databases, AI platforms), cybersecurity emerges as a non-traditional challenge. One participant noted a real example of a cyber breach at a firm that led to loss of electronic field data. Similarly, using third-party AI services raises questions about data privacy and intellectual

property – for instance, uploading internal reports to an AI could inadvertently expose confidential information.

***Winter and Remote Site Constraints***: On a very practical level, the challenges of climate and geography were mentioned. Many innovative techniques or equipment face operational challenges in harsh conditions. For example, winter in cold regions can severely limit bioremediation activity, cause equipment (like drones or sensors) to fail or require special housing, and make site access difficult. Remote sites might lack internet connectivity (though solutions like Starlink were discussed as emerging options). These real-world constraints mean that even proven technologies must be adapted to field conditions – a challenge that technology developers and practitioners need to continuously address through engineering controls, contingency planning, and seasonal scheduling.

### 4.3 Innovative Technologies

***AI-powered Site Analysis Tools***: The use of artificial intelligence was a cornerstone of the innovation discussion. Large language models and machine-learning algorithms are being applied to rapidly generate CSMs, analyse complex datasets, and even draft reports. For instance, AI can scan historical well logs and outcome data to suggest optimal new sampling points or predict where contamination might have migrated. Specialized "co-pilot" AI systems, potentially kept internal for data security, are envisioned to assist project scientists by automating baseline analyses and highlighting anomalies – effectively acting as a junior analyst to speed up decision-making.

***Trium Field Screening Device***: A frequently cited technology was the Trium field analyser, an AI-enabled portable soil screening tool. This device can measure contaminant concentrations (such as hydrocarbons or salinity) on site within minutes and uses machine learning to correlate its sensor readings with lab results. By deploying tools like Trium's, teams can delineate contamination extents in real time and make immediate field decisions – for example, guiding an excavation to just the right depth and area – thereby saving time and reducing the number of samples sent to off-site labs.

> Drone technology equipped with cameras and sensors (including near-infrared spectroscopy, LiDAR, thermal imaging, etc.) is emerging as a powerful aid for remediation projects.

***Drones and Remote Sensing (NIR/Spectral Imaging)***: Participants described using drones for site reconnaissance – mapping contaminated areas, monitoring bioremediation progress via vegetative indices, and even detecting surface contamination signatures with spectral imaging. Near-infrared (NIR) and other spectral tools can help identify hydrocarbon presence or soil changes indicative of contamination from the air. This enables more comprehensive coverage of large or inaccessible areas (e.g., wetlands, steep terrains) and supports data gathering for conceptual site models without extensive ground surveys.

***Generative AI for Visualization***: The workshop discussed applying generative AI techniques to create or enhance visual representations of sites and data. For example, generative models can produce draft CSM diagrams, cross-sectional illustrations of subsurface plumes, or risk communication infographics based on input data. Participants even experimented with prompting image-generation AIs to draw site cross-sections, finding the results interesting but acknowledging they require careful vetting for accuracy. As this technology matures, it could reduce the time needed to prepare clear visuals for reports and stakeholder presentations, though human oversight is necessary to ensure the outputs are scientifically correct.

***High-Resolution Subsurface Characterization Tools***: Several cutting-edge geotechnical and geophysical tools were highlighted for improving site characterization. These include direct-push high-resolution conductivity probes, membrane interface probes, and continuous core scanners that can map contaminant distribution with much finer detail than traditional drilling. By obtaining thousands of data points (e.g., sensor readings every few centimetres down boreholes), practitioners can create detailed 3D models of contamination, identify small lenses of impact, and design more precise remediation systems. Also mentioned were ISMs where many small samples are combined to get a representative average, reducing data variability and lab costs.

***Portable and On-site Labs (Mobile Analytical Units)***: The concept of mobile labs or on-site analytical trailers was discussed as an innovation to speed up analysis turnaround. These are field-deployable units equipped with instruments like gas chromatographs, X-ray fluorescence (XRF) analysers, or immunoassay kits, capable of providing lab-quality results on location. In the workshop, the use of such mobile labs (potentially housed in trailers or vans) was cited to reduce chain-of-custody delays, avoid shipping samples, and adjust sampling plans immediately based on results. One table debated their value, noting they can be very effective on remote projects or when quick decisions are needed, though method standardization and cost can be challenges.

***Phytoremediation and Biotechnologies***: Bioremediation and phytoremediation technologies were recognized as innovative approaches that harness natural processes. Examples included using plants like willows, poplars, or switchgrass to extract or break down pollutants in soil, and bio-stimulation techniques such as adding specific nutrients or amendments (e.g., agricultural alfalfa pellets) to boost indigenous microbial degradation. Fungal remediation (mycoremediation) using species like oyster mushrooms to degrade hydrocarbons, and bioaugmentation with lab-cultured microbes for contaminants like chlorinated solvents, were also mentioned. These biotechnologies offer a more sustainable, low-impact clean-up method and can often be implemented in situ, though they may require longer timeframes and careful monitoring.

Modern GIS-based remediation platforms allow teams to layer chemical data, geology, and infrastructure in three dimensions, which greatly aids understanding and communication of complex sites.

***Spatial Data Management and 3D Visualization Software***: Another technology area is improved software for spatial data integration and 3D visualization. Some participants referenced tools that can ingest high-density data (from drones, direct-push, etc.) to produce interactive 3D models of contamination plumes. These visuals help in explaining site conditions to stakeholders and can be used to run "what-if" scenarios (e.g., how a certain remediation technique might clean different layers). As more data become available, such software can incorporate time series to show how conditions evolve, essentially creating digital twins of contaminated sites.

***Advanced Sensors and Internet of Things (IoT)***: The advent of robust, low-power sensors and IoT connectivity is opening new frontiers in monitoring. Autonomous sensors that continuously measure parameters like groundwater quality, gas emissions, or leak detection, and transmit data in real time, were highlighted for their ability to provide high-frequency datasets. Examples include networked piezometers that log water quality data, or sensor arrays for leak detection in pipelines. These can feed into machine learning models to detect anomalies or optimize remedial system operations. The challenge is ensuring these devices are calibrated, secure, and maintained – but their use can significantly enhance early warning of issues and reduce the need for manual sample collection.

***Virtual Reality and Remote Collaboration***: As a forward-looking idea, some participants touched on using virtual reality and augmented reality for training and remote site visits. VR can simulate contaminated site conditions for training purposes, allowing new staff to practice identifying contamination or implementing a remediation system in a risk-free virtual environment. It can also enable remote experts to "walk through" a site virtually, guiding field teams without travel. While not mainstream yet, the combination of VR with detailed 3D site models, drones, and real-time sensor feeds could soon allow regulators and experts to assess site conditions from afar, which is especially valuable for hard-to-access locations.

# 5 SESSION 1: LEVERAGING INNOVATION THROUGHOUT THE REMEDIATION LIFE CYCLE

## 5.1 Session 1 Summary

This session set the stage by examining how emerging innovations – from alternative remediation methods to AI – can be applied at each phase of a cleanup project. Participants shared success stories and challenges. A major focus was on reducing heavy dependence on landfill disposal by using validated treatment technologies. For example, one case study described an alfalfa-based bioremediation trial that achieved rapid petroleum breakdown in soil, illustrating the potential of nature-based and in-situ treatments to restore sites at lower cost than "dig and dump" methods. The group acknowledged, however, that adoption of such innovations has been slow, pointing to entrenched obstacles: landfilling's low cost and immediate liability transfer, short budgeting cycles that discourage multi-year pilots, and regulatory risk aversion that makes regulators hesitant to approve unproven techniques.

Despite these barriers, the session brought forward concrete ideas to de-risk and mainstream innovative approaches. One theme was building industry-led validation programs – essentially, collaborative pilot projects and "proof-of-concept" studies funded by operators (potentially with government support) to provide data on new methods. Participants emphasized the importance of early regulator involvement in such pilots to align on goals and foster trust; regulators could help define success criteria so that if a pilot meets them, the technology has a clearer path to acceptance. The session also highlighted the role of academic and third-party experts ("validators") as neutral parties to assess results, and the need for strong consultant + contractor + technology vendor teams to bring diverse expertise to demonstration projects.

> There was consensus that AI is an enabling technology – it can crunch numbers and reveal patterns far faster than humans – but expert oversight remains essential to verify AI outputs and make judgment calls (preventing "black box" decisions).

Participants explored how artificial intelligence and data analytics can accelerate the remediation lifecycle, from site assessment to reporting. They discussed using AI to aggregate and interpret site data (such as combining geospatial maps with lab results to improve conceptual site models) and deploying field decision-support tools. Attendees noted that innovative sampling tools, when combined with cloud databases, can greatly speed up delineation of contamination, though they require robust data management (large training datasets, rigorous quality assurance) to be effective. Additionally, the group considered the value of physics-based AI modelling (e.g., machine-learning-augmented groundwater models) to predict contaminant transport and guide remediation design.

Throughout the session, the human and organizational factors were front and centre. Participants underscored the need for strong project teams and knowledge sharing. Successful innovative

projects often had the right people at the table: experienced field practitioners providing practical insights, technology specialists fine-tuning the tools, engaged regulators offering guidance, and management backing the effort. The session stressed ensuring senior oversight and mentorship – e.g., having veteran field supervisors involved when trialling a new technology to troubleshoot issues and adapt the approach in real time. Also, better internal and external communication of results was deemed crucial: when an innovative approach works, the team should prepare a clear, concise takeaway to present to others (both within their organization and to the broader industry). This helps build momentum and support for scaling up the approach.

In sum, Session 1 painted a picture of cautious optimism. It recognized that leveraging innovation in remediation requires overcoming serious cost and culture hurdles, but it also demonstrated through real examples that new technologies – from bioremediation to AI – can deliver better, faster, cheaper results in certain contexts. The session concluded with a call to extract key lessons from these discussions and integrate them into the final workshop recommendations, ensuring that the ideas on innovation would be communicated to the full audience and decision-makers in a compelling way.

### 5.2 Opportunities

***Accelerate Validation Through Joint Industry Projects***: Participants saw an opportunity for companies to band together (potentially with government support) to co-fund pilot studies of promising remediation technologies[7]. By sharing the cost and insights of trial projects – for example, a multi-year bioremediation experiment or a demonstration of an AI tool across several sites – industry can collectively generate the proof needed to convince regulators and internal management of a method's efficacy. This shared validation model would spread risk and create a larger data pool than any single project, expediting the learning curve.

> One idea was creating "regulatory sandboxes" for environmental tech – essentially, controlled environments where regulators temporarily relax certain requirements to pilot a new approach under close observation.

***Regulatory Sandboxes and Early Engagement***: There is an opportunity to establish a more collaborative regulatory approach for innovation; including early and frequent engagement with regulators on specific innovative projects was viewed as critical. By involving regulators as advisory partners (rather than only gatekeepers), project teams can identify what data or safeguards would satisfy the authority, increasing the likelihood of acceptance for novel techniques.

---

[7] See for example Emissions Reduction Alberta projects: https://www.eralberta.ca/projects/details/in-situ-electrokinetic-remediation-of-salt-and-organic-impacted-soils/ and https://www.eralberta.ca/projects/details/downhole-imaging-system-for-identifying-wellbore-leakage/

***Leverage Experienced Practitioners as Innovation Advocates***: Several senior professionals in the session noted that they could act as champions or mentors for innovative projects. There is an opportunity to formalize mentorship programs where seasoned experts guide pilot projects or the integration of new tools, ensuring lessons learned are applied and training younger staff in real time. These "innovation ambassadors" can also help communicate successes to industry peers and regulators, lending credibility and building trust in the results.

***Integrate AI to Optimize Remediation Design***: AI algorithms could be used during the design phase of remediation to compare alternatives and optimize decisions. For example, AI could rapidly evaluate dozens of remedial options (dig-and-dump vs. in-situ treatment vs. monitored natural attenuation) for a given site, factoring in cost, time, and risk to produce a ranked list of strategies. This kind of decision-support tool, if developed, could help project managers and stakeholders objectively see the benefits of innovative methods (or combinations of methods) that might not be immediately obvious through manual analysis.

***Real-time Monitoring and Adaptive Management***: The session pointed out the opportunity to implement adaptive management in remediation – adjusting strategies on the fly as new data come in – thanks to real-time monitoring and analytics. By installing continuous sensors (for groundwater quality, vapour emissions, etc.) and using rapid field tests, teams can track remediation progress in near-real time. This creates the opportunity to shorten project cycles: for instance, ending a treatment phase as soon as objectives are met, or switching strategies if something isn't working. Embracing an adaptive mindset, enabled by real-time data, was highlighted to improve outcomes and efficiency.

> Participants saw an opportunity to reframe success metrics in remediation from achieving "zero contamination" to managing risk to human health and the environment. This shift would open the door for using innovative techniques that control risk (like encapsulating contaminants, phytostabilization) as acceptable endpoints.

***Focus on Risk and Exposure Reduction***: By focusing on actual exposure pathways and risk reduction (e.g., using in-situ stabilization to prevent contaminants from leaching, even if some contamination remains in place), projects could be closed more quickly and cost-effectively. The session encouraged development of guidance on risk-based closure and training for both regulators and practitioners in risk communication.

***Data Standardization and IT Investments***: Another clear opportunity is improving the digital infrastructure. Stakeholders can push for industry-wide data standards (consistent formats for reporting soil and water data, use of common units, required metadata like coordinates for each sample). Software investments, such as enterprise environmental data management systems or GIS platforms, can turn raw data into accessible knowledge – enabling advanced analytics and cross-site learning. Developing a shared data repository for regional background levels

(e.g., natural soil concentrations of certain compounds) was one concrete idea[8]; this would help companies avoid repeatedly sampling to establish what "clean" looks like in an area and could streamline risk assessments.

***Cross-disciplinary Collaboration***: Many innovations lie at the intersection of disciplines – for instance, combining agronomy with remediation for phytoremediation, or computer science with hydrogeology for predictive modelling. Thus, an opportunity exists to foster cross-disciplinary collaboration. This could mean hiring staff with non-traditional backgrounds (data scientists, botanists, etc.) into remediation teams, or partnering with external experts in fields like robotics, chemistry, or IT. By breaking out of silos, remediation practitioners can discover novel solutions and adapt technologies from other sectors (for example, borrowing remote sensing techniques from precision agriculture or adopting data analytics methods used in finance for risk modelling).

> Developing compelling case studies and visual tools was seen as key to improved stakeholder communication – e.g., creating intuitive before-and-after visualizations of a bioremediation project's success, or infographics comparing carbon footprints of landfill vs. in-situ treatments.

***Communication and Stakeholder Engagement***: The group identified an opportunity to improve how we communicate the value of innovative remediation to stakeholders. This includes educating clients and the public that "clean enough" (risk-based) may be more sustainable than "absolutely clean," or that a longer treatment can be preferable to immediate excavation because it offers a better environmental outcome. Enhancing communication will build broader support and understanding, which is needed for innovations to be accepted.

***Benchmarking and Knowledge Retention***: The session noted an opportunity to create a formal mechanism for capturing and sharing lessons from innovative projects. This could be an online knowledge base or annual forum where companies publish brief case studies of "what worked and what didn't." Particularly for negative outcomes (innovations that fell short), having a way to share that information confidentially or anonymously could prevent others from repeating the same mistakes. Some suggested an industry clearinghouse under a neutral party (such as a regulator or research institute) to gather these insights. Over time, this would serve as a benchmarking resource to guide future innovation efforts, ensuring continuous improvement.

### 5.3 Challenges

***Economic Disincentives for New Methods***: Landfilling contaminated soil is usually straightforward and relatively cheap, especially in regions where landfill tipping fees are low. In contrast, novel treatments may require significant upfront investment (for equipment, trials, or longer project durations) that can be hard to justify to management. This cost differential is a

[8] See, for example, Shelby-James et al. (2022).

fundamental challenge – innovative methods must either become much cheaper or be justified by demonstrating substantial value (e.g., avoided future liabilities, sustainability benefits) to gain traction.

***Strict Regulatory Criteria and Uncertainty***: Many participants felt that regulations – while crucial for safety – are not structured to accommodate innovation. Remediation rules tend to be prescriptive (specifying how to sample, which standards to meet, etc.), leaving little flexibility for alternative approaches. Furthermore, the outcome uncertainty of new methods (will the regulator accept this closure?) looms large as a risk. This challenge is compounded by the lack of a formal pathway for approval of new technologies in many jurisdictions. Without clear guidelines on how to get a new method approved (or how to petition for a variance), companies may stick with conventional methods to ensure compliance.

***Data Limitations for AI and Modelling***: As highlighted, "garbage in, garbage out" applies to digital innovation in remediation. A challenge is that much of the existing site data is incomplete, unstructured, or of variable quality. For instance, older sites might have only summary reports without raw data, or soil sample locations not accurately surveyed with GPS. These limitations hinder the training of AI models and the reliability of predictive simulations. The group recognized that significant effort might be needed to clean and standardize historical data – a painstaking task that organizations find challenging to prioritize amid active project pressures.

> Some participants pointed out that if an innovation threatens existing business models (for instance, reducing the volume of soil sent to commercial landfills), there may be institutional resistance from those whose business or jobs are tied to the old way.

***Cultural Resistance and Change Management***: Introducing new technology or practices also confronts the classic challenge of change management. The session noted some practitioners' scepticism or lack of familiarity with novel tools. For example, field crews may trust their own observations over a sensor reading, or project managers may be reluctant to rely on an algorithm's advice for a million-dollar decision. Overcoming this human resistance requires demonstrations, training, and building trust in the tools.

***Ensuring Quality and Accountability with Automation***: As more processes become automated or AI-assisted, maintaining accountability and quality is a challenge. Who is responsible if an AI system's recommendation leads to a decision that falls short? The session debated this, especially in regulatory contexts where professional sign-off is legally required. For now, the consensus was that human professionals (engineers, geoscientists) must remain the final decision-makers, using AI as a tool. But this raises a related challenge: professionals need to understand enough about these technologies to explain and defend how decisions were made.

Developing that competency in the workforce takes time and is an ongoing challenge as tools evolve.

***Liability and Risk of Failure***: Trying something new inherently carries the risk it may not work as expected. In remediation, a failed attempt can mean wasted time and money – and possibly regulatory non-compliance if cleanup goals aren't met. The fear of failure (and the potential regulatory enforcement or reputational harm that could follow) is a big challenge to overcome. Some participants noted that this makes companies favour incremental tweaks over bold changes. There's also the question of liability: if a new approach underperforms, who is accountable? These concerns underscore the need for carefully designed pilot projects and perhaps regulatory flexibility (like not penalizing initial pilots that don't fully meet targets) to reduce the downside risk of innovation.

***Scale-up and Generalization***: Even when an innovation succeeds in a pilot, scaling it up to different sites or broader use can be challenging. Site conditions vary widely (soil type, climate, geology, contamination mix), so a technology that works in one context might need significant adaptation elsewhere. For instance, a bioremediation technique effective in a warm climate might slow down in arctic conditions, or an electrical heating method might be infeasible near utilities or in a wetland. This challenge of scale-up means that innovators must be prepared for iterative learning and customization.

> One-size-fits-all solutions are rare – part of the challenge is building a toolbox of options and knowing when each is applicable, rather than seeking a single magic bullet.

***Resource and Capacity Constraints***: Implementing an innovative project can demand considerable time, skilled personnel, and equipment – resources that are often stretched thin. The industry is frequently operating under tight deadlines with heavy workloads, leaving little slack to experiment. Additionally, certain innovations require specialized equipment or analytical capabilities that may not be readily available (for example, a mobile lab or a particular sensor). Limited access to these resources is a practical challenge. It was mentioned that even when money is available, procurement and logistics for new equipment can introduce delays. Therefore, planning and securing the necessary resources well in advance is a challenge that must be managed for successful innovation deployment.

***Communication Gaps and Silos***: Another subtle challenge is communication – both within project teams and between different stakeholder groups. Complex innovations require cross-disciplinary understanding; for example, data scientists must communicate with geologists, or remediation engineers with ecologists in the case of nature-based solutions. Bridging language barriers between different fields and keeping discussions focused on objectives is an ongoing challenge. Similarly, communicating results from technical staff up to executives or to

community stakeholders in an understandable way is non-trivial and can affect whether an innovation is given the green light or not.

**Ensuring Follow-through and Measuring Impact**: Implementing innovation requires diligent project management and persistence. Organizations need to set metrics to measure the impact of new approaches (e.g., reduction in remediation time or cost, improved compliance outcomes) and track these over time. Without measuring and publicizing the benefits, it can be challenging to justify continued support for innovative practices.

# 6 SESSION 2: SAMPLING AND ANALYSIS: THE REMEDIATION BACKBONE

## 6.1 Session 2 Summary

This session zeroed in on field sampling practices and laboratory analysis as the foundation of effective remediation. The discussion covered how to integrate new technology into sampling workflows while preserving the irreplaceable value of expert human observation. One focus was on AI-based field screening tools and their potential to complement traditional lab sampling. Attendees noted that in a recent project these tools achieved high accuracy and offered real-time feedback to guide field decisions. However, the group emphasized that such tools cannot fully replace conventional sampling and human judgment. Field test results must be interpreted with caution – for instance, acknowledging their variability and confirming key findings with accredited laboratory analyses.

> Participants agreed that "you can't fix what you haven't properly found" – robust sampling and analytical data are essential for accurate site characterizations and successful cleanups.

Several practical challenges in current sampling and lab processes were highlighted. Participants shared frustrations with the "nuts and bolts" of sampling: chain-of-custody errors, packaging mistakes, and communication gaps with labs were cited as issues that lead to delays or data quality problems. It was noted that as laboratories consolidate and experience pricing pressures, the personal interaction between field personnel and lab chemists has decreased, making it harder to troubleshoot unusual results. The session also delved into emerging contaminants like PFAS (per- and polyfluoroalkyl substances), where laboratory capacity and validated methods are lagging industry needs. For example, participants mentioned long turnaround times and limited lab availability for PFAS analysis, as well as supply chain issues for specialized sample containers and standards. This underlined that sampling and analysis protocols must continually evolve to keep up with new contaminants.

Human expertise and training emerged as a recurring theme. There was widespread agreement that while gadgets and software are improving, the insight and adaptability of field scientists and technicians remain crucial. Participants stressed the enduring importance of on-site observational skills – recognizing subtle signs of contamination (like staining, odours, soil texture changes) that instruments might miss or misinterpret. Thus, an important point was that adopting digital tools should not come at the expense of training field crews in fundamental skills and conceptual thinking. In fact, some attendees observed a decline in field experience and mentorship (e.g., younger staff not receiving the same level of hands-on training as previous generations), which can lead to avoidable sampling errors such as cross-contamination, mislabelled samples, or missed locations. The consensus was that mentorship programs and formal training on both traditional techniques and new tech (like tablet-based logging, GPS usage, etc.) are needed to maintain a high standard of data quality.

The session also explored innovations in sampling strategies and technology. One approach discussed was using CSMs more dynamically to guide sampling: rather than rigidly following default grid patterns, teams can update CSMs as new data come in and focus sampling where it will reduce uncertainty the most. The idea of Integrated Sampling Methodology (ISM)[9] – combining multiple increments of soil into one sample to get a representative average – was raised to improve representativeness and possibly reduce lab load. Additionally, some tables debated the value of mobile field labs and on-site analytics. For example, bringing a portable lab to the field can expedite analysis, but capacity is limited – so a hybrid approach (field screening to guide where critical lab samples are taken) was considered the ideal in many cases.

> On the technology front, participants talked about tablet-based field data collection, using GIS-enabled software for logging sample information on the fly and even employing satellite internet (e.g., Starlink) to synchronize data from remote sites in real time. These digital tools can cut down transcription errors and allow for immediate data sharing with off-site experts.

Laboratory processing and turnaround times were another focus. Participants lamented that sample turnaround has lengthened in recent years, partly due to increased demand and reduced lab staffing or expertise. This delay can stall project decisions. Some creative solutions were offered, like forming closer partnerships with labs to prioritize important samples, exploring new lab methods that could be faster (e.g., modified extraction techniques for quicker results on salinity), or even investing in in-house lab capabilities for big projects.

One action item captured in the session was for technical leads to investigate lab method modifications (such as skipping time-consuming steps like air-drying and grinding soil for certain analyses) to speed up results without sacrificing quality. Another was a suggestion for senior industry professionals to advocate for investment in better field test kits for challenging parameters (like chloride) and push for regulatory acceptance of their data where applicable.

Finally, the session touched on operational efficiencies and coordination. Beyond technology, improvements in how sampling programs are planned and executed can yield big benefits. For instance, aligning sampling schedules with equipment and crew availability, and coordinating between operators and consultants to avoid duplicated efforts, were noted as ways to increase efficiency. One idea was to develop a standardized "field readiness checklist" or use digital project management tools to ensure all necessary equipment (coolers, preservatives, backup parts) are in place – a response to common mishaps like missing preservatives or faulty equipment causing re-sampling. The session found that many such issues are practical and procedural, implying that innovation isn't only high-tech – sometimes it's simply improving planning and communication.

---

[9] See https://ism-2.itrcweb.org/

Overall, Session 2 reinforced that accurate, timely sampling and analysis are the bedrock of any successful remediation. The participants identified both high-tech and low-tech ways to strengthen this foundation: from adopting AI and field sensors, to improving training, to streamlining lab interactions. The insights from this session set the stage for incorporating technological advancements in the critical early phases of remediation projects, ensuring that subsequent decisions are based on solid data.

### 6.2 Key Points

***Field Data Quality is Paramount***: The session reiterated that effective remediation begins with getting the right data from the field. Participants agreed that all the fancy models and remedies in the world won't succeed if your sampling is flawed or your lab data are suspect. Thus, maintaining high standards in sampling protocols, documentation, and lab analyses remains point #1 – the "backbone" of remediation.

***Human Touch vs. Automation***: While technology can augment data collection, experienced field scientists and technicians catch critical details – soil smells, discolouration, subtle stratigraphy changes – that instruments might miss or misinterpret. The group emphasized that training and mentorship are needed to ensure that the next generation retains these observational skills, even as they use tablets and sensors. In short, digital tools must support, not supplant, the insight of seasoned field personnel.

***Integration of AI-based Screening Tools***: The session devoted much attention to blending AI-driven field screening tools into traditional sampling programs. For instance, crews can use such tools to test multiple points in real time and focus confirmatory sampling only on areas that screen "dirty," potentially reducing the number of lab samples and avoiding delays. Participants saw these tools to make field programs more dynamic, and data driven.

***Caution with Screening Results***: Conversely, it was also pointed out that field screening results have limitations and must be treated with care. A high reading on a handheld XRF or photoionization detector (PID) indicates a hotspot but doesn't always equate to a lab exceedance due to interferences and lower accuracy. The group agreed that field tests are incredibly useful for rapid feedback, but final decisions (especially for regulatory closure) still hinge on conventional laboratory confirmation. This point reinforced the complementary role of new tools – they enhance the process but don't eliminate the need for lab-quality data and expert interpretation.

| Field screening data should "guide, not decide." |
|---|

***Laboratory Process Bottlenecks***: Participants shared that sample shipping, preparation, and analysis can introduce weeks of lag – slowing down projects. They recounted instances of lost or mislabelled samples and reduced ability to talk through results with lab chemists due to automation or lab staff turnover. The prevailing view was that improving communication and

setting up clear protocols with labs (for example, pre-scheduling analyses, utilizing courier tracking for samples, and establishing points of contact for problem-solving) is vital to ensure data comes back swiftly and correctly.

***Emerging Contaminants and Capacity Gaps***: The session also tackled challenges with emerging contaminants (like PFAS) that test the limits of current lab and field capabilities. Members noted that methods for PFAS in environmental samples are still being refined and that few labs are equipped, leading to long turnaround times and high costs. Additionally, sampling for PFAS requires special precautions (to avoid Teflon, certain ice packs, etc.) which field teams are still getting up to speed on. This discussion highlighted a need for ongoing innovation in analytical chemistry and for regulators to provide interim guidance on how to handle such contaminants while science catches up.

***CSMs to Guide Sampling***: Instead of treating a CSM as a static figure in a report, participants advocated updating the CSM in real time as new data arrive and using it to target additional sampling. For example, if early sampling data suggest contamination is limited to a certain stratigraphic layer, the CSM can be updated and subsequent samples focused on delineating that layer. This approach can reduce random sampling and ensure that field efforts are addressing the highest uncertainties.

***Mentorship and Training for Field Staff***: Reiterating a cross-cutting concern, session attendees pointed out that skilled field personnel are essential and currently in short supply. The group sees a need for more formal training programs, field apprenticeship opportunities, and retention of experienced workers as mentors. Some companies are instituting internal certification programs for samplers. Without a strong foundation of human expertise, even the best technology won't yield reliable results – this was an important contextual point.

There's an opportunity to develop best-practice checklists or standard operating procedures that incorporate new tools and ensure nothing is overlooked in the field.

***Standardization and Best Practices***: Participants identified variability in how sampling and analysis are conducted between different companies (and even between teams within a company) as something that can be improved. For instance, establishing a standard procedure for using a field XRF device (to ensure consistent calibration, reading technique, and documentation) would improve data comparability. Additionally, creating a standard "minimum dataset" for submissions – e.g., always including cross sections, tables of detection limits, and rationale for not sampling certain media – could reduce back-and-forth with regulators and elevate the quality of all submissions.

***Connecting Field and Lab Data Through Technology***: The session noted the promise of new software tools to bridge field activities and lab analysis. For example, using digital chain-of-custody apps to track samples can prevent mislabelling and instantly alert the lab of incoming

samples. Advanced Laboratory Information Management Systems[10] that interface with field data collection tablets could allow results to be automatically uploaded and linked to specific sample locations in a GIS. Some companies are exploring blockchain for secure sample tracking (to ensure data integrity from field to lab to reporting). Embracing such technologies can fortify the reliability of the sampling-analysis continuum, ensuring that what is measured in the lab can be confidently tied back to exact field conditions in space and time.

### 6.3 Challenges

***Field Screening Limitations and Trust***: A prominent challenge discussed was the variable reliability of certain field test kits and screening methods. For example, participants described issues with commonly used chloride field test strips (quantabs)[11], which were criticized for inconsistencies and interferences, leading to frequent under- or over-estimation of salt levels in soil. This has eroded some practitioners' trust in field kits. As a result, crews often default to sending more samples to the lab, lengthening projects. Overcoming this requires either improving the technology (more accurate field kits, better calibration) or developing clear protocols on how and when to use them so that their results are dependable.

***Lab Capacity and Turnaround Delays***: Laboratory turnaround times for sample analysis are often a bottleneck in remediation projects. Standard turn-around time for many analyses can be weeks, which slows decision-making. In some cases, labs are backlogged or have reduced capacity for specialized tests (e.g., PFAS, emerging contaminants), further delaying results. Rush analysis is expensive and not always feasible for large sample batches. Thus, a challenge is how to get timely data without prohibitive cost. Potential solutions (mobile labs, on-site tests) come with their own challenges (limited scope, need for regulatory acceptance), so teams often feel stuck waiting on lab data.

> The "last mile" of getting a quality sample to the lab is fraught with potential human errors – mislabelled bottles, broken or lost samples, expired preservatives, etc.

***Human Error and Sample Management***: Session 2 provided anecdotes of how simple mistakes in the field or during shipping have led to data being unusable and required costly resampling. Even small errors like a chain-of-custody form filled out incorrectly can cast doubt on data validity. This challenge persists despite technological advances and points to the need for rigorous training and possibly digital aids (like barcode systems or smart checklists) to reduce human error.

---

[10] See https://en.wikipedia.org/wiki/Laboratory_information_management_system

[11] See https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/canadian-conservation-institute-notes/test-chloride-ions-iron-treatment.html#a3

***Declining Lab Interaction and Expertise***: Several veteran practitioners lamented that the traditional practice of field scientists communicating directly with lab chemists has dwindled. In the past, one might call the lab to discuss strange results or request customized analyses, but now interactions are often reduced to electronic forms and reports. This can be a challenge when nuanced judgment is needed, such as determining if a lab result might be an outlier due to an artifact. Combined with reports of decreasing lab staffing and experience levels (e.g., fewer seasoned analysts to notice something amiss in a chromatogram), there is a risk of blind spots in data quality. Essentially, as labs automate and scale up, the opportunity for professional judgment and consultation may be diminishing – a challenge both labs and practitioners need to manage.

***Emerging Contaminants – Analytical Uncertainties***: With new pollutants like PFAS, 1,4-dioxane, and various emerging chemicals on the radar, analytical methods are often playing catch-up. Additionally, regulatory standards for these chemicals are evolving, and methods must detect ultra-low concentrations (parts per trillion for PFAS), which push the limits of current lab instruments. This presents a challenge: field and lab personnel must be trained in these new protocols, and false positives/negatives must be carefully managed to avoid misguided remediation efforts.

***Volume of Data vs. Actionable Insights***: As projects integrate more tech and collect more data points (from high-res sampling, continuous monitoring, etc.), they face the challenge of data overload. Simply gathering thousands of data points is not helpful unless they can be translated into clear decisions. This challenge emphasizes the need for robust data management and analysis tools (like visualization software or AI) to interpret large datasets – otherwise, teams may default to traditional low-density data just because it's familiar and easier to interpret.

| It's easy to get "drowned in data but starved of insight." |
|---|

***Operational Logistics and Coordination***: Several challenges were practical. For instance, when doing large field programs, aligning drilling crews, sampling teams, and analytical labs in schedule is a complex dance – if communications falter, people can be on standby or equipment underutilized. There was mention of instances where lack of coordination led to multiple mobilizations to the same site or sampling being redone because a minor but required component (like a particular sampling pump or a cooling trailer for summer sampling) wasn't in place. Overcoming these logistical challenges requires good project management and perhaps better use of tools like digital scheduling boards or project management software.

***Quality vs. Speed Trade-offs***: A challenge inherent in sampling and analysis is balancing speed with quality. Everyone wants data faster, but the session cautioned that rushing can compromise reliability. For example, doing a quick grab sample from a borehole might save time but could yield non-representative data if the sample isn't handled properly or if the heterogeneity of the site isn't captured. Similarly, field test kits offer speed but less accuracy. The group recognized

this trade-off as a constant challenge – knowing when a rapid answer is "good enough" for a decision versus when a high-confidence answer is needed, justifying a slower, rigorous approach. Developing decision frameworks for this (i.e., when to rely on screening vs. when to insist on full lab data) is part of that challenge.

***Chloride and Salinity Management Issues***: In many regions, salt (chloride) contamination from produced water or brine is a prevalent issue. A specific challenge is that field measurement of chlorides is unreliable with current tools, yet lab methods for salinity are time-consuming and not always representative (e.g., the common requirement to dry and grind soil can skew chloride results). This leaves practitioners in a bind, sometimes leading to multiple mobilizations when lab results come back different from field expectations. Tackling this challenge might involve developing better field chloride sensors, revising lab methods (like analysing wet samples to preserve actual conditions), or reconsidering regulatory thresholds/approaches for salts.

***Alignment of Sampling with Risk and End-use***: The session touched on how current sampling requirements sometimes don't align well with actual risk or site needs. For instance, some guidelines demand certain numbers of samples even on low-risk sites, which can consume resources with little added benefit. Conversely, if initial site models are poor, sampling might miss critical areas (e.g., not sampling groundwater when it should have been). Ensuring the sampling and analysis plan is proportionate to the problem – neither under- nor over-doing it – is a challenge that requires experience and sometimes pushing back on one-size-fits-all requirements. The group noted that improving conceptual models and having open dialogue with regulators about what data are truly necessary for decision-making can help address this issue.

# 7 SESSION 3: OPPORTUNITIES FOR INCREASING TECHNOLOGY-ENABLED REMEDIATION

## 7.1 Session 3 Summary

Session 3 expanded on the earlier technology discussions by identifying concrete opportunities to deploy more technology in remediation and to overcome the barriers hampering their adoption. The conversation recognized that while many innovative tools exist or are in development – high-resolution site characterization, AI, remote sensing, bespoke treatment technologies – the challenge is often institutional (funding, approvals, knowledge gaps) rather than purely technical. A large portion of the session concentrated on why promising remediation innovations often don't scale or become mainstream. Participants pointed to factors like funding constraints, intellectual property and competitive pressures, and a lack of platforms to share successes and failures. For example, companies may be reluctant to share data from a failed pilot due to reputational concerns, meaning others cannot learn from those lessons. Additionally, they noted that many clients default to "tried-and-true" methods (like excavation) partly because of tight project timelines and the immediate certainty those methods provide – a cultural inertia that technology proponents need to address with strong value cases.

A key theme was the role of funding and collaboration in advancing technology. Participants explored various models: leveraging R&D tax incentive programs (such as SR&ED[12]), partnering with industry research organizations (e.g., PTAC or Natural Gas Innovation Fund – NGIF[13]), and engaging academic institutions through sponsored research or graduate projects. These avenues can inject resources and fresh ideas into technology development. The session gave examples of successful collaborations, such as company-funded PhD research that led to new soil stabilization techniques, or government-supported pilots for new groundwater treatment methods. Nonetheless, securing funding remains difficult, especially for smaller firms, and intellectual property concerns can make companies hesitant to collaborate openly.

> The consensus was that blended funding models (public-private partnerships) hold promise to drive innovation in ways purely private or public efforts might not.

Regulatory acceptance (again) was a major point of discussion. It was noted that in some cases, regulations may need updating to accommodate novel approaches – for example, allowing alternative endpoints or recognizing surrogate parameters. Participants gave an example of how prior regulator investments (like guidance on risk-based Tier 2 closures) can inadvertently

---

[12] See https://www.canada.ca/en/revenue-agency/services/scientific-research-experimental-development-tax-incentive-program.html

[13] See https://www.ngif.ca/

entrench certain methods and make newer ones seem like outliers. One opportunity identified was engaging regulators to accept analogous evidence – for instance, using visualizations or indirect measures to demonstrate remedy effectiveness. A specific idea was using AI-driven 3D visualizations of contaminant distribution and risk to support discussions with regulators, bridging the gap between raw data and risk decisions. Another was the concept of pre-approving the use of certain technologies in a controlled manner – e.g., a guidance or directive that encourages the use of field screening data for interim decision-making, provided certain quality assurance steps are followed.

The session also highlighted numerous technology opportunities on the horizon for remediation. These included advancements in on-site thermal and chemical treatments (like portable smouldering units for hydrocarbon-impacted soils, or electrokinetic systems to treat clays) that could handle contaminants in place. Stakeholder engagement (such as with Indigenous communities in reclamation projects) was cited as both a challenge and an opportunity: involving local stakeholders can improve project design and acceptance and potentially yield collaborative solutions (like using traditional knowledge for land restoration techniques).

> There was creative discussion around beneficial reuse of treated materials – for example, treating contaminated soil to standards that allow it to be reused as construction fill, thus avoiding waste generation.

An interesting angle was the suggestion to establish a "technology clearinghouse" or hub for remediation innovation – a platform modelled after organizations like the Interstate Technology and Regulatory Council or regional innovation hubs, where validated case studies, performance data, and best practices for new technologies can be aggregated and disseminated. This could help overcome the information-sharing barrier by providing a semi-formal channel for learning about what works. Session 3 participants also touched on policy incentives – for instance, adjusting financial or regulatory incentives (like landfill taxes or performance-based cleanup contracts) to favour treatments that achieve environmental risk reduction and sustainability rather than simply moving waste around.

In summary, Session 3 was forward-looking, scanning the horizon for technological leaps and asking "what will it take to get there?". It balanced excitement for new tools (AI, advanced treatments, big data, automation) with a realistic appraisal of the structural changes needed (funding, policy tweaks, culture shift). The discussions in this session built upon earlier ones by fleshing out a roadmap of opportunities – giving the workshop concrete ideas to refine into recommendations for increasing the role of technology in remediation practice.

### 7.2 Key Points

***Tapping Into Innovative Treatments***: The session catalogued various cutting-edge remediation techniques that hold promise. These ranged from enhanced bioremediation (using microbes, plants, or fungi) and soil washing for hydrocarbon or metal removal, to electrokinetic

remediation in low-permeability clays, and thermal desorption for volatile contaminants. Each technology has shown success in certain pilot or full-scale applications, but participants noted none are yet a panacea – indicating the need to match the right technology to the right site conditions.

***Scaling Innovation Remains Difficult***: Many technologies succeed in one-off trials but fail to scale across the range of site types and contaminants. Reasons include lack of funding for multiple demonstrations, IP restrictions (companies guarding proprietary methods), and insufficient documentation of results. The group noted that even when an innovation works, it might not spread because people in the industry don't hear about it in detail. This highlighted the classic "valley of death" in innovation – bridging from research/pilot to routine practice is a key challenge the industry must consciously address.

***Regulatory Conservatism vs. Innovation***: Participants observed that regulatory frameworks can unintentionally favour established methods. For instance, guidelines typically lead proponents to proven approaches (dig-and-dump, pump-and-treat, etc.) but are less clear on how to approve something novel like an AI-based risk assessment or a new reagent for in-situ chemical treatment. This conservatism can protect against snake oil, but it also slows adoption of legitimately better methods. The session emphasized the need for regulators to develop guidance and criteria for new technologies – such as how to evaluate an AI's recommendations or what constitutes acceptable evidence of bioremediation success – to give innovators a clear target to meet.

***Funding and Incentives for R&D***: An important point was that increased funding and incentives are required to spur technology R&D in remediation. Remediation is often seen as a cost to minimize, so companies invest relatively little in R&D compared to, say, exploration or production. Ideas to counter this included leveraging government innovation grants (where available) and tweaking economic incentives (for example, higher disposal fees or tax credits for on-site treatment) to make the business case for innovation more attractive. Additionally, participants suggested that big operators could dedicate a small percentage of their remediation budgets to an innovation fund that supports trials of new approaches, ensuring continual improvement.

> A neutral, respected body could verify and disseminate treatment technology information, helping practitioners make informed decisions and reducing duplication of effort.[14]

***Knowledge Exchange and Hubs***: Session 3 attendees strongly felt the lack of a robust mechanism to exchange knowledge on new remediation technologies. They discussed the potential of creating a central knowledge hub or network (like a library of case studies, or an

[14] InnoTech Alberta or an academic institution could fill such a role.

online platform) where practitioners can find information on past projects, vendor offerings, and performance data.[15]

***Harnessing Big Data and AI for Risk Prioritization***: Building on previous sessions, the group articulated that beyond individual sites, AI could be used at a portfolio level to prioritize remediation efforts across many sites. For instance, a machine learning model could analyse a company's entire portfolio of sites and rank them by risk to human health and environment, flagging which sites might benefit most from a novel remediation approach. This would help allocate resources more efficiently. The challenge is feeding such a system with standardized data from all sites (again pointing to the need for data standardization). This point envisions a future where technology not only improves individual projects but also strategic decision-making across portfolios.

***Public Engagement and Transparency***: An often-overlooked area of innovation is in how projects engage with the public and stakeholders. Session 3 noted opportunities for improving transparency using technology – for example, providing communities with access to real-time monitoring data through web dashboards, or using augmented reality to show residents what remediation is happening beneath their feet. Another idea was to share "open data" for remediated sites, so academics or citizen scientists could analyse and perhaps find patterns or solutions that professionals missed. Embracing transparency can build public trust and might even invite fresh perspectives on longstanding remediation challenges.

> The remediation industry can look laterally for innovation – technologies proven in other fields that could be repurposed for environmental cleanup.

***Adapting Successful Tech from Other Sectors***: Oil and gas logging tools for high-resolution subsurface imaging, drones and remote sensors from the agriculture and mining sectors for environmental mapping, or advances in chemical engineering (like catalysis or nanotechnology) for breaking down pollutants could be deployed in the remediation space. By staying attuned to other industries, remediation professionals can import solutions rather than inventing everything from scratch. One opportunity is to strengthen cross-sector collaboration – attending other industry conferences or partnering with tech companies – to scout for adaptable technologies.

***Encouraging a "Try-Fail-Learn" Culture***: The session implicitly made clear that to increase tech-enabled remediation, the culture must allow for some failures in pursuit of better methods. There is an opportunity to create an environment where innovative attempts are not punished but seen as learning experiences – provided appropriate safeguards are in place. This could involve regulators being more flexible in granting extensions or variances when a new method encounters hiccups, or companies recognizing staff who take initiative to try improved methods

---

[15] The Canadian Conservation and Land Management Network (CCLM – https://www.cclmportal.ca/) is an example of a knowledge hub.

even if outcomes are not 100% as expected. Creating this culture of innovation is a soft, but crucial, opportunity that was recognized: success will breed more success, but someone must go first and others must not be afraid to follow.

***Combining Multiple Innovations***: Lastly, participants noted that often the biggest gains come from integrating several technologies or techniques rather than any one in isolation. For example, one might combine high-res site characterization (to pinpoint contamination) with targeted in-situ remediation (like focused injection of amendments) guided by an AI model – achieving far better results together than any single innovation would alone. The opportunity here is to design pilot projects and full-scale remedies that intentionally bundle complementary innovations. This systems approach can address the complex, multi-faceted nature of remediation projects. However, it also raises the complexity of execution and analysis, which means such combined innovation projects need careful planning and interdisciplinary coordination (tying back to the challenge of team integration and project management).

### 7.3 Challenges

***Translating R&D to Real Projects***: A central challenge identified is the gap between research and actual field implementation. Many technologies show promise in the lab or on paper but moving them to real contaminated sites involves uncertainties that can deter decision-makers. For instance, a novel chemical oxidant might work in a controlled setting but encounter unexpected interactions in heterogeneous field conditions. Bridging this gap requires not only technical tweaks but convincing stakeholders to sponsor and risk a field trial. Workshop participants noted that without a mechanism to support this "translate to field" stage (such as funding and pilot programs), many innovations stall after R&D.

> Unlike some industries where open innovation is common, environmental remediation firms often consider their methods and data proprietary.

***Intellectual Property and Competition Issues***: This competitive attitude creates a challenge: companies may be reluctant to share details of an innovative process they've developed, fearing loss of competitive edge. This slows collective learning – others cannot build on that innovation or may waste resources repeating similar work. Resolving this may require new business models (e.g., joint ventures that commercialize a technology) or clearer intellectual property agreements that allow sharing of results while protecting commercial interests.[16]

***Limited Regulatory Pathways for New Tech***: Session 3 emphasized the lack of clear regulatory pathways for approving or crediting new technology as a significant challenge. This means

[16] NOTE: The Premier's 2025 mandate letter to the Minister of Technology and innovation provides direction on co-investments in technology developers and ownership interest in intellectual property (https://www.alberta.ca/technology-and-innovation).

innovators must negotiate on a case-by-case basis, which is time-consuming and uncertain. Evolving the regulatory framework to include performance-based outcomes and technology-specific guidance is a complex but needed endeavour.

***Access to Capital for Innovation***: Implementing tech-heavy solutions can require significant capital investment (for equipment, specialized personnel, etc.), which is a barrier especially for smaller firms or site owners. Many technology vendors in this space are startups or small companies that also struggle with funding and market penetration. This challenge means that some technologies never get fully developed or tested because the required investment is hard to secure without guaranteed returns. The group discussed using existing funds (like Canada's SR&ED tax credits) or forming industry pools to address this – but until such mechanisms are robust, the funding barrier remains a primary challenge for technology-enabled remediation.

***Stakeholder Perception and Buy-In***: Persuading all stakeholders – not just regulators, but also clients, local communities, and sometimes even one's own organization – to accept a new approach is challenging. For example, a client may be uncomfortable with a novel method on their high-profile site for fear of negative optics or investor concerns. The challenge is to effectively communicate how the technology works, its safety, and its benefits (in cost, time, or outcomes) in terms each stakeholder values. Session 3 underscored the need for demonstration projects that also serve as communication tools – e.g., inviting stakeholders to site visits or preparing explanatory materials – to build trust in the methods.

> A community might be wary if told contamination is being left to degrade naturally, equating that with inaction, unless it's clearly communicated that the approach is safe and monitored.

***Balancing Innovation with Reliability***: Many in the session confronted the innovation paradox: stakeholders desire improvements but often default to methods with a proven track record. One challenge is that new technologies can introduce new modes of failure or uncertainty – for example, a complex in-situ system might encounter unexpected subsurface conditions that nullify its effectiveness, whereas digging out soil carries fewer unknowns. Balancing the pursuit of innovation with the obligation to ensure a reliable outcome is a persistent tension. Often, hybrid approaches are used (e.g., treat part of a site with new tech but also have a fallback plan for conventional treatment if needed), but this can increase costs. Developing contingency plans and fail-safes for innovative treatments was identified as a necessity to address this challenge.

***Soil Reuse***: One specific example of a challenge discussed was the difficulty in getting soil reuse initiatives off the ground. Even after treatment (like thermal desorption or soil washing), regulators and the public can be hesitant to allow the reuse of treated soil due to fear of residual contamination. This results in treated soil often still going to a landfill or confinement facility, negating some of the sustainability benefits. The challenge is to develop standards and verification methods that all parties trust for declaring treated materials "clean enough" for reuse.

Similar technology-specific challenges were noted for others (e.g., the need for QA/QC standards for 3D-printed reactive materials, or durability concerns for permeable reactive barriers).

***Long-Term Stewardship and Monitoring***: Some technology-enabled solutions (like in-situ bioremediation or stabilization) require long-term monitoring and possibly maintenance, which can be seen as a drawback compared to the one-and-done nature of excavation. Ensuring that there are robust long-term stewardship plans and that future resources are committed for monitoring decades out is a challenge. This is especially true when site ownership changes or corporate memory fades. The session flagged the need for establishing clear, enforceable monitoring requirements and contingencies for innovative remedies – for example, what happens if an in-situ treatment doesn't perform as expected after five years? Without clear answers, regulators may default to requiring more conservative measures.

***Keeping Pace with Fast Tech Development***: Technology (especially digital tech) evolves rapidly, which is both a benefit and a challenge. By the time a particular tool (say, a specific software platform or sensor) gains traction in the remediation industry, a newer version or competitor might have emerged. This can make organizations hesitant to commit R&D or operational resources. There's also the challenge for regulators and standards bodies to keep pace with the change; guidance can lag new capabilities. This highlights a need for agility and continuous learning in the industry, but it remains a challenge for typically slow-moving processes to adapt quickly to innovation cycles.

> Nobody wants to invest heavily in what might become the "Betamax" of remediation tech.

***Piloting vs. Implementation Capacity***: Many attendees noted that while pilot projects are valuable, there's a tendency for innovative methods to get stuck in "pilot purgatory" – tested once or twice, then shelved. A challenge is ensuring that when pilots show success, they progress to full implementation. This might require a different set of skills and resources; scaling up often confronts new issues (e.g., sourcing of materials at larger scale, training more personnel, adjusting to different site conditions). Companies may have dedicated R&D teams for pilots, but those teams need to hand-off to operations groups for rollout – and that knowledge transfer can be challenging. The session identified the need for better integration between R&D and operations to ensure that successful pilots aren't just academic exercises but lead to change in routine practice.[17]

[17] While not specifically addressed in this summary, the concerns about pilot project capacity also applies to policy development.

# 8 SESSION 4: OPPORTUNITIES TO IMPROVE SUBMISSIONS: FROM PROBLEM TO SOLUTION

## 8.1 Session 4 Summary

The final session tackled the often overlooked but crucial endgame of remediation projects: the regulatory submissions and closure processes. Participants noted that even after good site work is done, poorly structured or overly voluminous submissions can delay site closure. Common issues include unclear CSMs in reports (e.g., missing cross-sections or incomplete source-pathway-receptor linkages), inconsistent inclusion of required information (like forgetting to address all APECs), and a lack of concise rationale for decisions made during remediation. Regulators in the session emphasized they often receive reports with "data dumps" but without clear narratives explaining, for example, why groundwater was not investigated or how background conditions were considered – prompting iterative requests for more information.

> How can we make regulatory interactions – particularly the preparation and review of remediation closure reports (such as site remediation completion reports and risk assessment submissions) – more efficient, transparent, and conducive to innovation.

One key opportunity discussed was to move toward standardizing and digitizing the submission process. Alberta's OneStop system was given as an example: it has reduced lost files and enforces that certain fields are completed. However, participants noted OneStop's rigid form can lead to odd outcomes – for instance, it might flag minor issues (like a natural background exceedance) as a problem requiring further action, even when professional judgment says it's not a concern. Despite such quirks, the consensus was that electronic submissions with structured data are the future. If done right, this allows for automated checks (ensuring key elements are included) and potentially triaging of sites – e.g., simple low-risk cases could be auto-approved, freeing up regulator time for complex sites. The session proposed opening non-sensitive portions of these databases (post-closure) for broader data mining, which could help industry and regulators identify trends and improve practices (for example, learning from all sites where a certain approach was used).

Improving the quality of submissions was another major theme. Attendees shared tips for crafting better reports: always include a clear executive summary and CSM; use tables and graphics to make the case (e.g., tables that compare pre- and post-remediation concentrations, maps that show residual impacts vs. receptors). A strong recommendation was to present a consistent, evidence-backed narrative of "from problem to solution" – explaining how each area of concern was investigated, what the results mean, and why the chosen remedial actions are protective of receptors. Regulators noted they value submissions that plainly justify decisions, such as not pursuing groundwater remediation because a pathway was demonstrated to be

incomplete. Conversely, lengthy reports lacking focus can obscure key information. Therefore, brevity and clarity were championed.

> A one-page summary sheet that tells the site story at a glance could be placed at the front of every submission.

The session also touched on the challenge of variable regulatory interpretation and enforcement. Practitioners lamented that outcomes can differ based on which individual reviewer you get – some may be very strict and request additional data for minor issues, while others are more pragmatic. In some regions, experienced "qualified professionals" have more latitude (like in British Columbia's system)[18], whereas in others, even minor deviations require regulatory approval. This variability adds uncertainty to the submissions process. A potential solution mentioned was increasing direct communication between submitters and reviewers, such as pre-submission meetings for complex sites to agree on expectations. Another idea was having regulators adopt a risk-prioritization system – focusing their detailed review on higher-risk sites and fast-tracking low-risk ones with minimal review, based on key indicators provided in the submission.

Finally, Session 4 reinforced that technology can assist the submissions and closure phase as well. For instance, GIS and database tools can generate much of the required content for a closure report automatically (maps, data tables, comparisons to guidelines) if data are managed properly. Some companies are exploring auto-generating portions of reports from their data management systems to ensure nothing is missed and information is presented consistently. The concept of knowledge management was touched on: organizations should track common deficiencies that regulators point out and develop internal checklists so that each new submission learns from past ones. A noteworthy suggestion was to include regulatory representatives in future workshop breakout or table discussions specifically dedicated to closure and submissions, as their direct input is invaluable – this session observed that having fewer regulators present was a missed opportunity to get real-time feedback on the ideas proposed.

In essence, Session 4 was about tightening the "last mile" of remediation. It identified that the greatest technology or remediation effort can be undermined by poor documentation or procedural delays at the end. The opportunities and challenges discussed aimed at ensuring that cleanup efforts are effectively translated into regulatory approvals and site closures, which ultimately is the measure of success for any remediation project.

### 8.2 Additional Points

***Need for Concise Executive Summaries***: A strong point was the value of a clear, one- to two-page executive summary at the front of every submission. This summary should outline the site

---

[18] See https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/professional-reliance

history, what was done (investigation and remediation), the results, and the conclusion (why the site is now in compliance or risks are managed). Regulators noted that when such a summary is present and well-crafted, it greatly speeds up their review – they can understand the whole story before diving into the appendices. It's essentially a courtesy and a critical communication tool that should not be skipped.

***Justification of Closure Decisions***: Regulators in the session emphasized that the "why" matters: submissions should clearly justify decisions like not remediating certain areas or proposing risk management over removal. This level of clarity addresses questions upfront.

> The point is that every deviation or decision (e.g., using a site-specific guideline, applying a risk assessment, etc.) should be backed by an explanation and data, rather than assuming the reviewer will infer the rationale.

***Handling Background and Exceedances***: An issue often encountered is dealing with readings that exceed criteria due to natural background conditions (for instance, metals or nutrients that are naturally elevated). Session 4 pointed out that submissions should proactively incorporate background studies and comparisons to distinguish anthropogenic contamination from natural levels. This might involve including regional background data or site-specific background sampling results. The challenge is twofold: assembling credible background data (sometimes requiring regulatory approval for methods) and then clearly communicating in the submission that certain "exceedances" are within natural norms. Doing this pre-empts the regulator's concern and demonstrates due diligence.

***Inconsistent Regulator Responses***: Participants noted that outcomes can vary with different regulators or even individual reviewers – what one accepts, another might question. This inconsistency is a frustration and a challenge. It points to an underlying need for ongoing training and calibration of regulators as well as consultants. Some in the session recommended more frequent meetings between regulators and practitioners (outside of specific project reviews) to discuss case studies and align expectations. While regulators will always have some discretion, increasing consistency was seen as beneficial. Until then, an effective submission strategy is to anticipate the "strictest" possible interpretation and ensure the report addresses requirements to that standard.

***Data Transparency and Accessibility***: There was a discussion about making better use of the wealth of data contained in regulatory submissions after project closure. Currently, a lot of valuable data remains siloed in individual reports. If non-confidential portions of this data (like soil background levels, remediation performance metrics) were made accessible through public databases or publications, it could inform future projects. The challenge is working out privacy and liability issues: site owners may fear that sharing data could invite scrutiny or liability. However, as one opportunity, regulators could anonymize and aggregate data from closed cases to publish trends (for example, typical ranges of cleanup times for certain contaminants, or

performance of particular technologies). This would turn regulatory archives into a learning tool, though it requires effort and policy support to implement.

***Emerging Tools for Better Submissions***: Templates and software that auto-populate report content from data (like generating tables of results against criteria, or plotting concentration trends) can reduce human error and ensure completeness. There are challenges here (like version control and ensuring narrative text is still well-crafted), but these tools could alleviate the tedium of assembling appendices and allow professionals to focus on interpretation. Embracing these could address the challenge of consistency and efficiency in reporting.

> Some participants are adopting report writing tools that link directly to their databases – if a lab result is updated, it flows into the report draft.

***Regulator Participation in Future Discussions***: A meta-challenge that came up is the need for more direct regulator participation in innovation discussions. This reflects the broader challenge that innovation conversations happen in industry forums and then have to be translated for regulators later. Bridging this gap by inviting regulators into the early conversation (and regulators being willing to engage in that way) remains a social/institutional challenge. Overcoming it could greatly smooth the path for implementing the improvements identified (since the regulators would be co-designing them).

# 9 SUMMARY, OPPORTUNITIES AND NEXT STEPS

## 9.1 Key Points Arising from the Workshop Discussions

Microsoft CoPilot provided the following summary of the key points in the Workshop. The information is provided in tabular format in Appendix 4.1.

***Need to Move Beyond Landfilling***: Participants stressed the importance of adopting on-site treatment and bioremediation technologies to manage contamination sustainably, citing successful field trials that achieved soil restoration at lower cost than hauling to landfills.

***Barriers to Innovation***: The workshop pinpointed major obstacles to new technology uptake. These include the low financial cost and convenience of landfilling (which undercuts the business case for alternatives), short corporate budget cycles that don't align with multi-year pilots, perceived liability transfer benefits of disposal, and regulators' cautious attitudes toward unproven methods. Any innovation strategy must reckon with these economic and institutional realities.

***AI's Emerging Role in Remediation***: Participants explored how artificial intelligence and machine learning are beginning to augment the remediation process. Concrete use cases included AI-generated conceptual site models for preliminary risk assessment, algorithms to suggest optimal sampling locations, and tools to digest decades of PDF reports into actionable insights. Physics-based modelling combined with AI was noted to help predict groundwater behaviour and delineate plumes.

> Overall, AI was seen as a powerful accelerator – but one requiring human QA/QC to prevent errors or "hallucinations".

***Field Screening and Real-time Data***: A recurring theme was the value of field-portable analytical tools to speed decisions. Participants highlighted the use of devices like Trium (an AI-enabled soil screening tool) to get near-instant contaminant readings on site. These tools, including drones with sensors, can guide excavations or sampling in real time by indicating "hot spots," thus reducing unnecessary sampling and lab wait times. However, it was noted that field readings must be correlated with accredited lab results and currently serve best as screening for quick decisions rather than final closure proof.

***Data Quality and Management Matter***: Many discussions underscored that the effectiveness of advanced analytics or AI hinges on having high-quality, accessible data. Common problems include important site data trapped in unstructured documents (scanned reports, etc.) and lack of geospatial referencing. Participants called for standardized electronic data formats (e.g., spreadsheets or databases instead of solely PDFs) and centralized data repositories to enable deeper analysis. They noted that current regulatory submissions (like ROSC reports) often provide only summaries, limiting the data available for modelling. Improving data management is seen as a prerequisite for successful digital innovation.

***Workforce and Training Gaps***: While AI might aid training by generating tutorials, participants strongly agreed that hands-on mentorship and knowledge transfer to the next generation of practitioners is essential. Maintaining senior oversight on projects implementing new technologies was recommended to ensure sound judgment (for example, having veteran professionals validate AI outputs and interpret field data).

> The human element in remediation remains critical. Attendees observed a decline in experienced field personnel and mentorship, which can lead to mistakes (e.g., sampling errors, misinterpretation) if not addressed.

***Regulatory Engagement and Risk-based Approaches***: A prominent point was the need for closer collaboration with regulators to enable innovation. Regulators at the workshop emphasized that they look for clear, concise justifications in submissions – e.g., why certain pathways are low risk or why certain data suffice. It was noted that when practitioners provide multiple lines of evidence (e.g., soil data, modelling, toxicology studies) in a well-structured format, it streamlines regulatory review. The group discussed moving toward more risk-based closure decisions, where costly additional remediation can be avoided if risk assessments show negligible benefit.[19] Regulators were encouraged to participate in pilot projects and help define the "rules of the game" for novel techniques, rather than only evaluating them at the final approval stage.

***Successes in Technology Trials***: The workshop heard encouraging reports of technology pilots yielding positive results. Participants shared that field pilot tests of innovative tools have shown high correlation with standard methods. For instance, one table reported that Trium's field screening device achieved approximately 90% agreement with laboratory measurements for hydrocarbons and chlorides in soil – demonstrating its reliability as a screening proxy. Another success noted was the use of high-resolution "direct push" sensor data to build detailed 3D subsurface models, which helped optimize well placements and focus excavation on truly impacted zones. These examples provide momentum and learning for broader implementation.

***Need for Action and Accountability***: Across all sessions, participants repeatedly observed that great ideas alone are not enough – follow-through is the challenge. Many past meetings have generated lists of recommendations that weren't acted upon. In this workshop, it was acknowledged that assigning clear owners and deadlines for next steps is crucial. Suggestions were made to have workshop organizers or committees champion certain initiatives (e.g., forming a task force to develop data standardization guidelines, or scheduling regulator–industry follow-up meetings to discuss pilot proposals). By improving project management and

---

[19] Alberta Energy and Minerals (2025) – Industry leaders highlighted that some of the most stringent closure requirements – particularly those related to … soil contamination (e.g., salt in the soil) – often result in diminishing returns in terms of environmental protection, while simultaneously driving up costs for operators and leading to unknown and/or uncertain outcomes.

"timeboxing" of tasks, the community can ensure that the insights from this workshop translate into measurable progress.

## 9.2 Opportunities to Move Remediation Innovation Forward

Microsoft CoPilot summarized the steps that each of the following organization types can take to improve remediation processes, practices and technology development and adoption:

***Regulators and Policy-Makers***

Regulators were repeatedly identified as key enablers (or blockers) of innovation. Steps regulators and policy makers can take:

- Shift toward risk-based remediation frameworks rather than rigid, one-size-fits-all numerical criteria, allowing site-specific solutions where risk to receptors is demonstrably low.
- Introduce flexibility for innovative approaches, such as monitored natural attenuation, in-situ treatment, and containment with controls, where supported by data.
- Create mechanisms to pilot or trial new technologies, such as regulatory "sandboxes" or controlled demonstration projects, to generate evidence while managing risk.
- Improve regulator-industry collaboration early in project planning, including pre-application meetings and joint workshops to reduce uncertainty around approvals.
- Align economic signals with sustainability goals, for example by reassessing landfill disposal incentives that currently favour "dig-and-dump."

***Site Owners / Responsible Parties (Industry)***

Industry decision-making and risk tolerance were central discussion themes. Steps industry can take:

- Move away from default landfill disposal by requiring that innovative or on-site treatment options be seriously evaluated before excavation and disposal.
- Adopt longer-term perspectives on remediation value, recognizing that landfilling transfers liability rather than resolving contamination.
- Support pilot projects for emerging technologies, especially when co-funded or risk-shared with government or industry programs.
- Invest in better data collection and site characterization, including real-time field analytics, to reduce uncertainty and over-remediation.
- Encourage internal cultural change by allowing calculated risk-taking and learning from both successful and unsuccessful remediation trials.

### *Environmental Consultants and Practitioners*

Consultants and practitioners were seen as critical translators between technology, regulation, and practical application. Steps consultants and practitioners can take:

- Use advanced site characterization and modelling tools to build stronger conceptual site models and justify alternatives to excavation.
- Apply risk-based thinking consistently, clearly linking remediation decisions to actual exposure pathways and receptors.
- Integrate real-time field analytics to reduce delays, over-excavation, and reliance on slow laboratory turnaround.
- Maintain strong human oversight of AI and data tools, ensuring that professional judgment validates automated outputs.
- Share lessons learned (where possible) from pilot projects to help build confidence in new methods across the industry.

### **Technology Developers and Vendors**

Technology providers were discussed in the context of trust, validation, and usability. Steps technology developers and vendors can take:

- Focus on field-proven reliability, particularly under challenging conditions (e.g., cold climates, remote sites).
- Generate transparent performance data through pilots and demonstrations that regulators and practitioners can evaluate.
- Design tools that integrate with existing workflows, rather than requiring wholesale process changes to adopt them.
- Position technology as decision support, not a replacement for professional expertise, to reduce scepticism and resistance.
- Engage early with regulators and end users to understand approval pathways and practical constraints.

### *Researchers, Academia, and R&D Organizations*

Research institutions were seen as important neutral testbeds for innovation. Steps researchers and their institutions can take:

- Pursue high-risk, early-stage remediation concepts (e.g., novel bioremediation, advanced treatment for salts or metals) that industry is hesitant to fund alone.
- Provide independent validation of technologies, helping separate effective solutions from poorly performing ones.
- Collaborate with industry and regulators to ensure research addresses real regulatory and operational barriers.

- Train the next generation of remediation professionals, emphasizing both innovative tools and foundational field judgment.

***Industry Associations, Funders, and Conveners***

Cross-sector coordination was repeatedly identified as missing. Steps industry associations, funders, and conveners can take:

- Establish shared innovation funds or co-funded pilot programs to lower financial risk for early adopters.
- Create centralized knowledge-sharing platforms for case studies, pilot results, and lessons learned.
- Facilitate collaboration among regulators, industry, and researchers through workshops and working groups.
- Recognize and reward innovation, helping shift industry norms toward sustainable remediation practices.

## 9.3 Additional Observations

The author and Workshop Committee members offered the following additional thoughts after reviewing the Workshop Summary.

### 9.3.1 *Proprietary vs. Non-proprietary Data*

Workshop participants identified value in accessing non-proprietary data to use in AI-driven data analyses. This issue has been raised previously with respect to creating and sharing various data sources and developing predictive mapping tools; see, for example, Drozdowski et al. (2019), Luchkow (2016), Richens and Patterson (2025), Shelby-James et al. (2021).

This suggests an opportunity to develop an inventory of data that would be considered non-proprietary, where are they housed, and how can they be accessed.

Possible online sources include AER's OneStop, EPA's Environmental Records Viewer[20], the Oil Sands Monitoring Program[21], the Alberta Biodiversity Monitoring Institute[22], Agricultural

[20] See https://geospatial.alberta.ca/erv

[21] See https://www.alberta.ca/oil-sands-monitoring-program-scientific-papers-and-data

[22] See https://abmi.ca/abmi-home/data-resources/data-portal-main/data-portal.html?rootPath=/&itemPerPage=6

Regions of Alberta Soil Inventory Database (AGRASID)'s Soil information Viewer[23], Saline Soils[24], GeoDiscover Alberta[25], Derived Ecosite Phase v1.0[26].

Access to other sources such as *Environmental Protection and Enhancement Act* (EPEA) approval annual report data may require requests to companies or a request under s. 35(1)(a) of EPEA (Government of Alberta, 2000):

> 35(1) Subject to this section,
>
> > (a) the following documents and information in the possession of the Department that are provided to the Department in the administration of this Act must be disclosed to the public in the form and manner provided for in the regulations:
> >
> > > (iv) environmental and emission monitoring data, and the processing information that is necessary to interpret that data, that is provided by an approval holder or a registration holder or provided pursuant to a code of practice;
> > >
> > > (v) any reports or studies that are provided to the Department in accordance with a term or condition of an approval or a code of practice;

The *Disclosure of Information Regulation* (Government of Alberta, 2004) describes the process to obtain the data.

Data from other sources such as research projects, university theses, and monitoring programs would require permission from the researchers.

Additional datasets are listed in Appendix C of the recently released *Directive for Reclamation Certificate Site Assessments for Pits and Quarries – Cultivated Land* (Alberta Environment and Protected Areas, 2026).

Wherever possible, data holders should be encouraged to provide for direct and easy access to data that will assist practitioners. Similarly, researchers and research organizations should be encouraged to remove paywalls and other obstacles to easy access to information that would assist practitioners and regulators.

### 9.3.2 *Electronic Data Submissions*

Participants identified a need for more electronic submissions with consistent data fields. One example of this not discussed at the Workshop is the AER's Reclamation Information System (RIS), a spatial reporting structure for annual conservation and reclamation activities, that was

---

[23] See https://soil.agric.gov.ab.ca/agrasidviewer/

[24] See https://open.alberta.ca/opendata/gda-2d0b0e82-8b17-4f48-af70-1a4940a8a8b4

[25] See https://geodiscover.alberta.ca/geoportal/#homePanel

[26] See https://open.alberta.ca/dataset/gda-00b21d9e-9428-47e6-baa3-08d57a6b95a0

developed collaboratively by industry and GoA as both saw value in standardizing reporting to help inform mine closure planning, regional planning, etc.

Use of RIS is required under *Direction for Conservation and Reclamation Submissions Under an Environmental Protection and Enhancement Act Approval for Mineable Oil Sands Sites* (Alberta Energy Regulator, 2018).

Adoption of data reporting standards could be considered foundational change supporting several other areas (e.g., data visualization, AI analytics).

### 9.3.3 *Bridging the Technology Development Gap*

Participants identified the gap between research and actual field implementation as a central challenge. There is an opportunity to develop an inventory of testing facilities of various scales that technology developers could access to help bridge the gap[27].

### 9.3.4 *Collaboration and Cooperation*

Collaboration and cooperation were seen as key to moving development, testing and adoption of technologies forward. While the concept has appeal, translating it into action requires longer-term program-level funding (rather than project funding) and a governance model that encourages participation representing all stakeholders. Funding ideas included a joint industry-government technology accelerator fund to subsidize pilot projects (e.g., an Alberta Innovates fund in the range of $50M to $100M).

There is an opportunity to capitalize on the enthusiasm in the Workshop by convening a group to explore a technology or process need that could be worked on using a model that has worked in the past. A recent example is the Soil Sterilants Program which identified and tested several sterilant remediation technologies (Drozdowski and Powter, 2024).

[27] See https://innotechalberta.ca/facilities/mesocosm-test-facilities/

## 10 REFERENCES


Alberta Energy and Minerals, 2025. Mature Asset Strategy: What we Heard and Recommendations Report. Alberta Energy and Minerals, Edmonton, Alberta. 51 pp. https://open.alberta.ca/publications/mature-asset-strategy-what-we-heard-and-recommendations

Alberta Energy Regulator, 2018. Direction for Conservation and Reclamation Submissions Under an Environmental Protection and Enhancement Act Approval for Mineable Oil Sands Sites. Specified Enactment Direction 003. 63 pp. https://static.aer.ca/prd/documents/manuals/Direction_003.pdf

Alberta Energy Regulator, 2025a. Contamination Management. Alberta Energy Regulator, Calgary, Alberta. Manual 021. 45 pp. https://static.aer.ca/prd/documents/manuals/Manual021.pdf

Alberta Energy Regulator, 2025b. Requirements for Site-Specific Liability Assessments. Alberta Energy Regulator, Calgary, Alberta. Directive 001. 16 pp. https://static.aer.ca/prd/documents/directives/Directive001.pdf

Alberta Environment and Protected Areas, 2024a. Alberta Tier 1 Soil and Groundwater Remediation Guidelines. Alberta Environment and Protected Areas, Edmonton, Alberta. Lands Policy, 2024, No. 1. 169 pp. https://open.alberta.ca/publications/1926-6243

Alberta Environment and Protected Areas, 2024b. Alberta Tier 1 Soil and Groundwater Remediation Guidelines. Alberta Environment and Protected Areas, Edmonton, Alberta. Lands Policy, 2024, No. 2. 120 pp.

Alberta Environment and Protected Areas, 2026. Directive for Reclamation Certificate Site Assessments for Pits and Quarries – Cultivated Land. Alberta Environment and Protected Areas, Edmonton, Alberta. EPA, Lands Policy, 2026, No. 2. 78 pp. https://open.alberta.ca/publications/directive-reclamation-certificate-site-assessments-pits-quarries-cultivated-lands

Drozdowski, B., C. Aumann and C.B. Powter, 2019. Predictive Soil Mapping Seminar: Summary Report. InnoTech Alberta, Edmonton, Alberta. 188 pp. https://www.cclmportal.ca/sites/default/files/2021-11/PSM%20Seminar%20Report%20-%202019%2003%2018%20reduced_2.pdf

Drozdowski, B. and C.B. Powter, 2024. Soil Sterilants Program: Knowledge Synthesis, Recommended Practices and Gaps. Report SSP-14B prepared by InnoTech Alberta and Enviro Q&A Services for Soil Sterilants Program, InnoTech Alberta, Edmonton, Alberta. 58 pp. https://www.cclmportal.ca/resource/soil-sterilants-program-knowledge-synthesis-recommended-practices-and-gaps

Government of Alberta, 2000. *Environmental Protection and Enhancement Act*. Chapter E-12. Government of Alberta, Edmonton, Alberta. 164 pp. https://kings-printer.alberta.ca/1266.cfm?page=E12.cfm&leg_type=Acts&isbncln=9780779785285

Government of Alberta, 2004. *Disclosure of Information Regulation*. Alberta Regulation 273/2004. Government of Alberta, Edmonton, Alberta. 3 pp. https://kings-printer.alberta.ca/1266.cfm?page=2004_273.cfm&leg_type=Regs&isbncln=9780779854332

Luchkow, R., 2016. Predictive EcoSite Mapping Project: Creating & Commercializing a Predictive Ecosite Classification Platform for Alberta. Prepared by Shore Pine Consulting Inc. for Alberta Biodiversity Monitoring Institute. 30 pp. https://abmi.ca/publication/499.html

Powter, C.B., 2024. Reclamation Workshop: Towards a Shared Foundation for Innovation and Evolution. Prepared by Enviro Q&A Services, Edmonton, Alberta, for Alberta Chapter/Canadian Land Reclamation Association. 116 pp. https://www.cclmportal.ca/resource/reclamation-workshop-towards-shared-foundation-innovation-and-evolution

Richens, T.C. and S. Patterson. 2025. Towards a Shared Foundation: Data/Innovation – From the Ground Up … Way Up. June 16, 2025 Workshop Summary Report. Prepared for Canadian Land Reclamation Association – Alberta Chapter and Alberta Innovates. 166 pp. https://www.cclmportal.ca/resource/towards-shared-foundation-datainnovation-ground-way-june-16-2025-workshop-summary-report

Shelby-James, N., S. Thacker, C.B. Powter, P. Fuellbrandt, T. Hengl and L. Parente, 2022. Alberta Background Soil Quality System Project: Workshop Summary. Prepared for the Petroleum Technology Alliance of Canada, Calgary, Alberta. Report 20-RRRC-11. 69 pp. https://www.cclmportal.ca/resource/alberta-background-soil-quality-system-project-workshop-summary

## APPENDIX 1 Pre-workshop Survey

***NOTE***: For the purposes of this survey, "work on" or "work in" includes any of the following activities related to remediation: field work, lab work, research, teaching, receiving and reviewing applications, setting or revising policy and legislation, conducting inspections/investigations, and developing and testing technologies, methods, processes, and tools.

### General

1. What best describes your primary role in remediation?

   Project Manager

   Industry Coordinator

   Laboratory Technician

   Field Technician

   Regulatory oversight

   Policy development

   Researcher

   Educator

   Business development

   Land manager / landowner

   Equipment/method/process development

   Equipment/product sales

   Other (please describe)

2. Which of the following sectors do you work in (select all that apply)?

   Upstream oil and gas

   Midstream oil and gas

   Downstream oil and gas

   Mining

   Aggregates (pits/quarries)

   Renewable energy

   Transportation/infrastructure

Industrial sites / plant sites

Municipal/commercial sites

Brownfield sites

Land manager / landowner

Others (please describe)

3. How long have you worked in the remediation field?

Less than 3 years

3 to 5 years

6 to 10 years

11 to 20 years

More than 20 years

4. Do you work on reclamation as well?

Yes

No

**Contaminant Types**

5. Which of the following contaminant types do you work on (select all that apply)?

Heavy end hydrocarbons (PHC fractions F2 to F4)

Light end hydrocarbons (BTEX, PHC fraction F1)

PAHs

Salts

Metals

Soil sterilants

Sulphur

Selenium

Mine tailings

Hydrovac waste

Radioactive materials / NORM

PFAS/PFOS

Others (please describe)

6. Which contaminant type is the most difficult to deal with (select one)?

Heavy end hydrocarbons (PHC fractions F2 to F4)

Light end hydrocarbons (BTEX, PHC fraction F1)

PAHs

Salts

Metals

Soil sterilants

Sulphur

Selenium

Mine tailings

Hydrovac waste

Radioactive materials / NORM

PFAS/PFOS

Others (please describe)

**Environmental Media**

7. Which of the following environmental media do you work in (select all that apply)?

Surface soil (<50 cm)

Subsoil

Bedrock

Confined aquifer

Unconfined aquifer

Wetland

Peat

Static surface waterbody (lake, pond, dugout)

Flowing surface waterbody

8. Which environmental media is the most difficult to deal with (select one)?

Surface soil (<50 cm)

Subsoil

Bedrock

Confined aquifer

Unconfined aquifer

Wetland

Peat

Static surface waterbody (lake, pond, dugout)

Flowing surface waterbody

**Innovation Needs**

In this section, please drag and drop the options to rank them from greatest (top) to least (bottom) importance.

9. Rank the following based on their need for innovation (greatest to least):

Modelling (e.g., CSM)

Field sampling design (e.g., location, depth, number of samples)

Field sampling equipment

Field analysis equipment

Lab sample preparation

Lab analysis

Treatment technologies

Data analysis

Data summary / reporting

10. Rank the following regulatory areas based on their need for innovation (greatest to least):

Guidelines values

Sampling requirements

Data submission requirements

Data submission processes

Liability assessments for sites with contamination

Post-remediation auditing

11. Rank the following impediments to remediation innovation (greatest to least):

Cost to develop

Cost to implement

Proprietary information/technology

Acceptance by industry

Acceptance by government/regulator

12. Are there other impediments to remediation innovation? If so, please describe.

Optional TEXT Entry

13. Rank the following in terms of their ability to accelerate remediation innovation (greatest to least):

Industry-academia partnerships

Regulator-practitioner working groups

Technology knowledge hubs

Annually updated list of RandD priorities

A common technology evaluation framework

Technology/project awards

14. Are there other options for accelerating remediation innovation? If so, please describe.

Optional TEXT Entry

**Closing Comments**

15. Do you have additional comments or observations to share?

TEXT Entry

## APPENDIX 2 Workshop Discussion Topics

### *Session 1. Leveraging Innovation Throughout the Remediation Life Cycle*

To achieve a desired remediation outcome, what tools (e.g., better data, AI) or technologies (e.g., materials handling equipment, sampling, treatment, data collection/recording, lab) are available, or needed?

At what stage(s) of remediation can AI and other innovative tools help?

How can AI help with policy development or refinement?

Can we harness technology (e.g., AI, portable sensors) to design better CSMs, field sampling designs, in-field and lab analysis, and site remediation?

What are the barriers to, and potential pitfalls of, regulatory submissions generated in part or in full by AI?

How would professional sign-off work for AI-generated submissions?

Does Errors and Omissions insurance cover you in case there is an AI-generated error?

How can AI-generated submissions be policed and by whom?

What professional expertise is required on a remediation team (e.g., CSM designer, field staff, information technologist, application coordinator) and what are their roles?

What expertise is required to develop, or use, new technologies or methodologies?

How can we mentor/train staff to adopt and innovate using the new technologies?

Whose job is that?

### *Session 2. Sampling and Analysis: The Remediation Backbone*

What are the main challenges and opportunities for field sampling?

Can we harness technology (e.g., AI) for better field sampling designs?

How do you deal with complex sites such as sites with multiple contaminants, complex geology, and/or where contaminants have migrated beyond a site boundary, or off-site?

In what ways can a CSM guide the development of field sampling strategies?

How do we use field results to modify the CSM (and when)?

When and how can field staff assist the CSM designer?

What are the main challenges and opportunities for lab analysis?

What role does sampling, packaging and transport of samples play in ensuring accurate lab analyses?

What feedback could be provided to field sampling crews to improve chances of success?

Does site type (location, private land vs. public land, urban vs. rural, provincial vs. federal, EPEA/MRDA approved vs. non-approved) change your approach to sampling and analysis?

Do we have the necessary systems in place to address sampling and analysis requirements for new contaminant types?

Who is responsible for developing the systems?

### *Session 3. Opportunities for Increasing Technology-enabled Remediation*

Where in the remediation life cycle is innovation most needed?

Is that where innovation is actually occurring?

What new field technologies (e.g., materials handling equipment, sampling, treatment, data collection/recording) and lab technologies are available or on the horizon?

How do you hear about them?

When and why would you consider adopting a new technology?

What are the barriers to technology innovation?

What role does policy/ regulation play to enable adoption of new technologies and processes, and what can be done to accelerate this?

How do you determine if a field or lab technology innovation is "successful"?

How can we foster RandD to get quicker adoption of new technologies and processes?

Who should fund remediation RandD?

Are there innovative funding approaches that could be explored?

Are there examples of successful RandD efforts?

What made them successful?

What lessons were learned?

What did we learn from the failed efforts?

Do we need a "Technology Hub" practitioners can refer to for best practices under various site types/contaminants?

If so, who would create and maintain it?

What would it contain?

### *Session 4. Opportunities to Improve Submissions: From Problem to Solution*

What are the common concerns regulators have about CSMs and how can they be addressed?

What are the common “problems” seen by regulators in applications and how can they be addressed?

What are the common “problems” practitioners see in regulatory requirements and how can they be addressed?

What types of additional information can be submitted that would improve chances of a submission being accepted?

Are there innovative tools or approaches required for sites with background concentrations above guideline values?

Which tools, methodologies, or justifications have proven effective in addressing guideline exceedances?

## APPENDIX 3 Workshop Participants

| | |
|---|---|
| Argel Alcobilla | Saskatchewan Research Council |
| Amit Bhargava | EnviroApps Inc. |
| Andrea Bullinger | Ram River Environmental Consultants |
| Trevor Burgers | Vertex Resource Group Ltd. |
| Michael Clark | Highland Environmental Consulting |
| Chelsea Clarke | Worley Consulting |
| Kim Cleland | Earthmaster Environmental |
| Cindy Craig | BBA Consultants |
| Marla Demoulin | British Columbia Energy Regulator |
| Jason Desilets | Cenovus Energy |
| Alanna Dickson | Montrose Environmental Solutions Canada Inc. |
| Adam Dunn | Earthmaster Environmental |
| Diana Dunn | Canadian Natural Resources Limited |
| Chase Edwards | Hodgson Contracting |
| Katy Edwards | Summit, An Earth Services Company |
| Lynette Esak | Alberta Energy Regulator |
| Sheldon Exner | Whitecap Resources Inc. |
| Justin Gregoire | ARC Resources Ltd. |
| Jesse Hahn | Natural Fibre Technologies |
| Tyrel Hemsley | Environment and Protected Areas |
| Chad Hohol | Cavvy Energy Ltd |
| Laura Jardin | Bowron Environmental Group |
| Heather Jones | Alberta Energy Regulator |
| Chris Kay | Terra Preta Organics |
| Jessa Kay | Bowron Environmental Group |
| Matthew Koehli | TerraLogix Solutions |
| Robyn Kuhn | Government of Alberta |
| Robert Lacey | Delta Remediation |
| Cristian Lazar | SLR Consulting Ltd. |
| Simone Levy | Waterline Resources Inc. |
| Dean MacKenzie | University of Alberta |
| Caryn Mann | Summit, An Earth Services Company |
| Michelle Martin | Calgary Aggregate Recycling |
| Margo Metcalfe | Ecoventure Inc |
| Elise Neumann | AECOM |
| Jennifer Nielsen | Good Lands Environmental |
| Matthew Nikkinen | Milestone Environmental |
| Patrick O'Neill | VEI Contracting Inc. |
| Abhijeet Pathy | University of Alberta |
| Shane Patterson | Alberta Innovates |
| Brent Phillips | Choice Environmental Consulting Group Inc. |
| Tyler Prediger | SLR Consulting (Canada) Ltd. |
| Matt Prier | Resolve Earthworks and Environmental |
| Jennifer Puhallo | Environment and Protected Areas |
| Ryan Puhlmann | GCL Environmental Ltd. |

| | |
|---|---|
| Oscar Pula | Keystone Environmental |
| Jim Purves | Northshore |
| Brett Reynolds | Shell |
| Tanya Richens | Canadian Association of Petroleum Producer |
| Keith Roscoe | Alfalfa Green Organic Fertilizers |
| Allison Routledge | Tetra Tech Canada Inc. |
| Paul Saunders | Independent |
| Carlene Schmidt | Trace Associates Inc. |
| Adam Semchuk | Alberta Energy Regulator |
| Steven Siciliano | LiORA and University of Saskatchewan |
| Danielle Siemens | ARC Resources Ltd. |
| Tara Smith | Canadian Natural Resources Limited |
| Dianne Stuart | Canadian Natural Resources Limited |
| Mike Tuyttens | Resolve Earthworks and Environmental |
| Kailyn Wiebe | Worley Consulting |
| Lily Yu | University of Illinois Urbana-Champaign/Corteva Agriscience |
| Kristen Zoerb | British Columbia Energy Regulator |

## APPENDIX 4 Tabular Summaries of Key Points, Opportunities, Challenges and Technologies

The content in sections 4.1 to 4.4 and 9.1 of this report is summarised in tabular form here.

### Appendix 4.1 Summary of Key Points

| Point | Frequency of Mention | Perceived Importance |
|---|---|---|
| **Economic Barrier of "Dig-and-Dump"**: Landfilling is often the cheapest and quickest solution (e.g., 27,000 $m^3$: $4M vs $14M for on-site treatment). This cost gap drives companies to favour hauling soil to landfills over investing in innovative remediation. However, participants stressed that this approach merely relocates contamination, leaving long-term liabilities. | Very High (repeated by many) | Critical – seen as the primary hurdle to adopting better remediation methods. |
| **Risk Aversion and Status Quo Culture**: There is a prevalent *we stick to what we know* mindset. Both industry and regulators often prefer conventional methods (excavation, disposal) over new techniques due to fear of failure and short-term performance metrics. This conservatism slows down the trial and adoption of innovative approaches. | Very High (strong consensus) | Critical – a cultural barrier that must shift to embrace innovation. |
| **Regulatory Inflexibility**: Current environmental guidelines (e.g., Alberta Tier 1 criteria) are rigid, leaving little room for site-tailored solutions. Novel methods (like using treated soil off-site or leaving low-level contamination in place with monitoring) face significant approval hurdles. Lack of mechanisms for fast-tracking innovations was noted as a bottleneck to trying new approaches. | High | High – modernization of regulations is needed to enable new technologies. |
| **Advocacy for Risk-Based Approaches**: The session strongly endorsed shifting from a rules-based to a risk-based remediation mindset. Instead of forcing all sites to meet generic standards, focus on actual risk to receptors. This could mean, for example, allowing a bit of contamination to remain if it's contained and poses no harm. Such approaches can save resources without sacrificing safety. | High | High – would optimize resource use and open doors for innovative solutions. |

| Point | Frequency of Mention | Perceived Importance |
|---|---|---|
| **Data and AI as Decision Support**: Better use of data analytics, AI, and modelling can improve decision-making. For instance, AI can help develop more dynamic CSMs or identify patterns in large monitoring datasets. Models were highlighted for predicting contamination spread and informing when natural attenuation or limited intervention is acceptable. Nonetheless, the quality of insights is only as good as the data input – *garbage in, garbage out* remains a concern. | High | High – key to smarter remediation, if data quality and human oversight are ensured. |
| **Real-Time Field Analytics Improve Efficiency**: New field-based testing tools can drastically speed up site characterization. The Trium portable lab device, for example, was reported to achieve ~90% correlation with lab results for hydrocarbons and salts, allowing teams to delineate contamination and confirm cleanup in the field rather than waiting days for lab results. This prevents over-excavation of clean soil and reduces project delays. | High | High – directly saves time and cost but needs broader acceptance and training to implement. |
| **Centralized & In-situ Treatment Concepts**: Ideas like regional soil treatment centres (to treat and reuse contaminated soil from multiple sites) and automated in-situ treatment units (solar-powered remediation systems that can run on remote sites) were discussed. These could provide economies of scale and tackle contamination on-site, reducing transport and waste. However, they would require changes in regulations (e.g., allowing inter-site soil transfer) and significant upfront investment.[28] | Moderate | High – could significantly reduce reliance on landfills if regulatory and funding barriers are overcome. |
| **Collaboration and Data Sharing**: The lack of knowledge-sharing was identified as a problem. Companies often repeat pilot projects and mistakes because results aren't widely shared (due to proprietary concerns). Participants called for more industry collaboration, possibly via consortia or a central innovation hub, so that successful pilots and lessons learned are accessible to all stakeholders and can accelerate collective progress. | Moderate | High – would speed up learning, build trust in new methods, and avoid duplication of effort. |

[28] See, for example, https://ccme.ca/en/res/excesssoilreuseguidance_en.pdf and https://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/soil-relocation

| Point | Frequency of Mention | Perceived Importance |
|---|---|---|
| **Funding & Incentive Mechanisms**: The group saw a need for financial incentives to support innovation. Ideas included a joint industry-government technology accelerator fund to subsidize pilot projects (e.g., an Alberta Innovates fund in the range of $50M – $100M). Another suggestion was raising landfill fees or imposing levies to better reflect the long-term costs of disposal. These economic levers would help make sustainable remediation options more competitive with the cheap dig-and-dump approach. | Moderate | High – pivotal to overcoming the upfront cost barrier of new technologies and practices. |
| **Human Expertise and Training**: Despite all the high-tech tools, experienced people remain irreplaceable in remediation projects. The know-how to interpret data, adjust to unexpected site conditions, and make judgment calls in the field was considered critical. However, there's worry that heavy reliance on AI or overly standardized processes could erode the development of new experts. Investing in training, mentorship, and human-in-the-loop systems is necessary so that innovation complements human expertise rather than displacing it. | Moderate | High – ensures competent application of technology and the continuity of professional expertise in the industry. |

## Appendix 4.2 Summary of Opportunities

| Opportunity | Frequency | Perceived Importance |
|---|---|---|
| **Adopt Risk-Based and Tiered Remediation Criteria**: Shift toward risk-based closure standards – allowing site-specific assessments to set cleanup targets when appropriate. This would focus efforts on actual environmental risks rather than requiring generic criteria everywhere, encouraging use of innovative solutions (e.g., monitored natural attenuation, on-site containment) when they can achieve acceptable risk levels. | High | High – Enables smarter, more cost-effective remediation by matching effort to risk. |

| Opportunity | Frequency | Perceived Importance |
|---|---|---|
| **Realign Economic Incentives (Make Landfilling Less Attractive)**: Use policy or market tools to reduce the appeal of hauling soil to landfills. Ideas included raising landfill tipping fees or limiting landfill disposal for certain contaminants. By internalizing the long-term costs of landfilling (e.g., perpetual monitoring, lost land use) or outright restricting it for treatable materials, alternative technologies would have a more level playing field. | Moderate | High – Directly drives innovation adoption by changing the cost/benefit calculation. |
| **Fund and Pilot New Technologies**: Establish a dedicated Remediation Innovation Fund (e.g., via Alberta Innovates or industry levy) to co-fund pilot projects of promising technologies. Shared-cost pilot programs would reduce financial risk for companies trying new approaches and generate data that benefits the entire industry. Open sharing of pilot outcomes (possibly through neutral parties like PTAC) is key to multiplying the impact. | Moderate | High – Jump-starts field validation of new methods and builds collective confidence through shared learnings. |
| **Create Central Treatment/Processing Hubs**: Develop regional soil treatment facilities where contaminated soil from multiple sites can be processed (e.g., biologically treated, soil washed) and then reused. This concept, already practiced in places like Ontario/Europe, could drastically reduce waste if regulations allowed transfer and treated reuse of soil. Similarly, mobile pop-up treatment units could be moved to pollution hot-spots for batch remediation campaigns. | Moderate | High – If regulations and logistics allow, could reduce landfill disposal and promote a circular economy for soil. |
| **Deploy Advanced Field Characterization Tools Broadly**: Encourage the wider use of real-time field screening and analytical tools. For example, the Trium AI-based soil analysis tool (with ~90% accuracy of lab results) could become a standard kit for delineating spills. Other opportunities include portable GC/MS for on-site water testing, drones with sensors for mapping spills, and robust EC (electrical conductivity) probes for salinity. Using such tools under a regulator-approved QA/QC protocol would enable faster, data-driven decisions on site. | High | High – Improves efficiency and reduces delays/waste in remediation projects. |

| Opportunity | Frequency | Perceived Importance |
|---|---|---|
| **Regulator-Industry Collaboration & "Sandboxes"**: Establish forums and processes for regulators and practitioners to collaborate on vetting new technologies. For example, a regulatory sandbox could allow controlled trials of innovative methods under relaxed rules to gather data. More practically, increasing pre-application meetings and joint workshops would help regulators become familiar with new techniques early and provide guidance on how to successfully get approval. | Moderate | High – Builds trust, aligns expectations, and smooths the path for regulatory acceptance of innovation. |
| **Transparent Data & Knowledge Sharing via Industry Hubs:** Create an accessible repository (possibly managed by an industry group or regulator) where companies can deposit and review results from remediation projects and pilot trials. This could include performance data of technologies, case studies, and even lessons learned from failures. Participants noted that a culture shift toward openness is needed – perhaps incentivized by government or industry recognition – to overcome proprietary silos that currently slow down collective progress. | Moderate | Medium/High – Reduces duplicated effort and accelerates learning, though it requires overcoming competitive barriers. |
| **Leverage External R&D and Student Engagement**: Increase partnerships with universities and research institutes to explore cutting-edge solutions (e.g., nanoremediation, phytoremediation with genetically optimized plants, etc.). Academic groups can often pursue high-risk ideas at lower cost (via grants, student projects) and serve as independent testers for vendor claims. Engaging students and researchers also helps train the next generation of specialists in innovative techniques. | Low/Moderate | Medium – Brings fresh ideas and validation capacity, though practical impact may be longer-term. |
| **Incentivize Innovation through Recognition and Policy**: In addition to funding, use soft incentives like awards, public recognition, or regulatory flexibility for innovators. For instance, if a company uses an on-site treatment that significantly reduces waste or emissions, regulators could expedite their review or provide credit in ESG (Environmental, Social, and Governance) scoring. Similarly, develop policy that *mandates reviewing innovative options* before resorting to disposal, effectively requiring justification for not using a more sustainable approach. | Low/Moderate | Medium – Helps shift organizational behaviour and signal the industry that innovation is valued and rewarded. |

| Opportunity | Frequency | Perceived Importance |
|---|---|---|
| **Improve Training and Knowledge Management**: Develop specific training programs for new technologies (e.g., certification courses for operating specialized equipment or using risk assessment tools). Also, capture the knowledge of veteran practitioners – perhaps through documented best-practice manuals or mentorship networks – so that experimentation and sophisticated analysis become part of standard practice. (The idea is to prevent brain drain and ensure that innovation is supported by strong practical know-how.) | Low/Moderate | Medium – Strengthens the human capacity needed to actually implement and trust innovative methods. |

## Appendix 4.3 Summary of Challenges

| Challenge | Frequency | Severity |
|---|---|---|
| **Cheap Disposal vs. Costly Treatment**: The economics of remediation heavily favour landfilling in regions like Alberta (described as possibly *the cheapest place to landfill*). In illustrative cases, landfill was a fraction of the cost of on-site treatment (see $4M vs $14M example). This makes it extremely hard for innovative but costlier technologies to compete when decisions are budget driven. | Very High (near universal) | Severe – fundamental barrier; companies default to landfill due to cost. |
| **Short-Term Mindset and Risk Aversion**: Companies and regulators often avoid approaches that don't guarantee success. There's low tolerance for risk – a failed remediation could mean redoing work at double cost. Combined with annual budgeting cycles that demand quick results, this leads to favouring "tried-and-true" methods over new ones. The unwillingness to accept even small risks significantly slows innovation adoption. | Very High | Severe – stifles experimentation and learning from pilots. |
| **Regulatory Rigidity and Red Tape**: Environmental regulations and criteria (e.g. fixed cleanup standards) can be inflexible. Innovative solutions that don't fit the existing mold face prolonged approval times or outright denial. For example, reusing treated soil from one site at another location might be prohibited as "waste movement." Similarly, leaving contaminants in place with institutional controls – even when risk is negligible – is often not allowed, forcing less optimal remediation by default. | High | High – causes promising solutions to be abandoned due to compliance hurdles. |

| Challenge | Frequency | Severity |
|---|---|---|
| **Data Silos and Lack of Shared Learning**: The industry's competitive nature means that data on new remediation techniques is not widely shared. Each company might run similar pilots without knowing that others have already tried and refined (or discarded) those approaches. This duplication of effort, and the failure to pool data, is a major challenge. It also means regulators see fewer *cumulative* successful case studies, making them more cautious in approving emerging methods. | High | High – slows collective progress and trust-building for new methods. |
| **Workforce Gaps and Experience Loss**: A looming shortage of experienced personnel – due to retirements and downturns – was highlighted. There is concern that as seasoned professionals leave, their practical knowledge of what works (and what doesn't) in remediation could be lost. Additionally, if routine tasks become automated (e.g., AI writing reports or analysing data), junior staff may miss out on learning opportunities, leading to a skill gap in the future. | High | High – threatens the industry's capability to implement and oversee innovative projects safely. |
| **Technical Limitations of New Tools**: Some cutting-edge technologies are still unproven or have practical constraints. The AI field analytics device (Trium), for instance, is highly accurate but was noted to struggle under extreme cold conditions without special accommodations. Similarly, other tools (like certain sensors or drones) may have reliability issues in rough terrain or harsh weather, requiring backups and increasing complexity. | Moderate | High – can hinder field deployment and confidence in new methods until resolved. |
| **Project Financing and Economic Cycles**: Several organizational challenges affect innovation, such as how projects are financed and how economic downturns disrupt R&D. Multi-year remediation projects with innovative elements may be hard to justify under annual budgeting. Also, when industry activity drops (e.g., oil price crashes), R&D budgets and experimental projects are often the first cut, interrupting momentum and causing talent to leave the field. | Moderate | High – structural challenge that can derail long-term innovation efforts. |

| Challenge | Frequency | Severity |
|---|---|---|
| **Inconsistent Guidelines Across Jurisdictions**: Companies operating in multiple provinces (or countries) face a patchwork of rules, adding complexity to innovation. A method accepted in one place might not be allowed in another. For example, risk-based closures or the use of certain models are routine in one region (like BC's use of risk-based closures with Approved Professionals) but not in Alberta. This inconsistency can deter companies from trying new approaches that won't be universally applicable. | Moderate | Medium – complicates the scaling of innovative solutions across projects and regions. |
| **Public and Stakeholder Perception**: Gaining buy-in from landowners, local communities, or Indigenous groups can be challenging, especially if the approach is to leave some contamination with monitoring (even if it's low risk). One participant noted that what regulators consider "remediation" might differ from what a community considers "restoration". If stakeholders distrust an innovative method, it can lead to project delays or rejection. | Low/Moderate | Medium – an important non-technical hurdle; must be managed through transparency and engagement. |
| **Legacy of Past Failures (Scepticism)**: Some innovations have under-delivered in the past, prompting scepticism. For instance, "snake oil" bioremediation products were tried on difficult sites (like alpine locations) with poor results, costing companies money without cleanup success[29]. These memories make both regulators and companies more cautious about new claims, creating a higher burden of proof for technology providers to overcome. | Low/Moderate | Medium – fuels the "prove it works first" attitude that can only be dispelled by robust demonstration data. |

[29] https://abinnovates-my.sharepoint.com/personal/shane_patterson_albertainnovates_ca/Documents/Microsoft%20Copilot%20Chat%20Files/Transcripts%20-%20Total%20-%20Session%201.pdf

## Appendix 4.4 Summary of Existing and Emerging Technologies

| Conceptual / Emerging Ideas | Already-Deployed Tools/Practices |
|---|---|
| **AI-Driven Decision Support for Remediation**: Using advanced AI to assist in designing remediation strategies – for example, AI systems that analyse historical project data and suggest the most effective remedial approach or optimal sampling plan for a new site.<br>*Status:* Conceptual; AI is not yet widely trusted for high-level decision-making in remediation (in part due to concerns about data quality and "black box" recommendations). | **AI-Powered Field Analytics (Trium Tool)**: A portable field lab device using AI/machine learning to analyse soil samples on-site for contaminants like hydrocarbons and salts.<br>*Deployed (pilot use)*: Trium has been used on spill sites in Western Canada, reportedly achieving ~90% correlation with lab results and significantly speeding up delineation and confirmation sampling. |
| **Autonomous In-Situ Remediation Units**: Solar-powered or automated treatment systems that can be left onsite to treat contamination with minimal human intervention (e.g., injection of amendments controlled by sensor feedback).<br>*Status:* Emerging concept; various prototypes (e.g., self-operating bioremediation rigs in trailers) were discussed, but not yet common practice. | **High-Resolution Site Characterization Tools**: Direct-push sensor probes (e.g., membrane interface probes, EC probes) and drones with cameras/sensors are already used to gather detailed site data.<br>*Deployed*: These tools help map contamination in real time (e.g., using a drone to survey methane or an EC probe to log soil salinity variations), though integration and acceptance varies. |
| **Centralized Soil Processing & Reuse Facilities**: A vision for regional centres where contaminated soil is treated (via bioremediation, soil washing, etc.) and then reused rather than landfilled. Would likely involve regulatory changes to allow moving and reusing soil between sites.<br>*Status:* Conceptual in Alberta; partial analogues exist elsewhere (e.g., soil banks in Europe, Ontario's soil reuse programs). | **OneStop Digital Submission System**: Alberta's online system for managing reclamation/remediation submissions.<br>*Deployed*: It's operational and was cited as an innovation in regulatory process – improving standardization of data collection for site closures. (Ongoing improvements are needed to better leverage the data and guide decisions.) |
| **AI-Assisted Risk Assessment Models**: Tools that could integrate vast data (toxicological databases, site-specific data, etc.) and automatically conduct or update site-specific risk assessments, suggesting which contaminants or exposure pathways warrant action.<br>*Status:* Conceptual; currently risk assessments are done by human experts using models like the Subsoil Salinity Tool (SST), but AI could enhance scenario analysis in the future. | **Subsoil Salinity Tool (SST) & Risk-Based Models**: Calculation tools (often Excel-based) used for site-specific guideline adjustment (e.g., Alberta's SST is used to derive site-specific chloride limits).<br>*Deployed*: These are widely used by consultants, though regulators still carefully review the inputs and results. |

| Conceptual / Emerging Ideas | Already-Deployed Tools/Practices |
|---|---|
| **Blockchain for Data Integrity in Sampling/Analysis**: The idea of using blockchain or similar technology to create tamper-proof records of sampling data, analysis results, and chain-of-custody, possibly linking lab results directly to a distributed ledger for transparency.<br>*Status:* Conceptual; raised as a future idea to increase trust in field data (e.g., ensuring no data manipulation). | **Mobile Labs & Portable Analytical Kits**: Small, trailer-mounted or vehicle labs that can do on-site analysis of contaminants (like petroleum hydrocarbons, metals).<br>*Deployed*: Some companies use mobile gas chromatograph labs or immunoassay kits at remote sites to get same-day results, reducing the need to wait for off-site lab results. These are in use but not yet widespread due to cost and logistical needs (calibration, skilled operators). |
| **Improved In-Situ Treatment for "Untreatable" Contaminants**: Research into technologies that can address contaminants currently considered difficult or impractical to treat on site, like heavy metals, salts, and emerging contaminants (PFAS). Examples mentioned include electrokinesis (using electric currents to mobilize contaminants) and advanced stabilizing amendments for salt-impacted soils.<br>*Status:* Experimental; being studied but not yet field-standard. | **Bioremediation with Amendments**: Using organic amendments to enhance natural biodegradation of hydrocarbons.<br>*Deployed* (pilot scale): In one pilot, mixing oily soil with alfalfa pellets achieved ~90% hydrocarbon degradation and cost only ~$25k (vs $100k for excavation). Such methods are in trial use, with the potential to restore soil health and support revegetation, though they require time and the right conditions. |
| **Advanced Data Integration & Visualization**: Development of platforms that integrate GIS, real-time sensor feeds, lab databases, and CSMs into one interface – essentially creating a digital twin of the site that updates as new data comes in.<br>*Status:* Conceptual; pieces exist (GIS, database software), but a seamless, AI-enhanced platform for remediation management is an aspirational goal. | **GPS-Guided "Smart" Excavation Equipment**: Construction machinery equipped with GPS and design software to guide excavation according to digital cleanup plans.<br>*Deployed (pilot use)*: Adapted from the construction industry, some remediation projects have tested GPS-enabled excavators to precisely remove only contaminated soil, which can reduce volume and avoid collateral damage. |

| Conceptual / Emerging Ideas | Already-Deployed Tools/Practices |
|---|---|
| **Proactive Training via VR and Simulation**: Using virtual reality (VR) to simulate contaminated sites for training, and AI-driven tutoring systems to teach complex skills (like interpreting geological data or running a risk model).<br>*Status:* Conceptual/Early-stage; such tools are being developed in other industries and were suggested to help train new environmental professionals more effectively. | **Digital Field Data Collection Apps**: Replacing paper field notes with apps (e.g., Fulcrum, Survey123[30]) on tablets for logging boreholes, sample locations, etc., with automatic upload to the cloud.<br>*Deployed*: Many teams use these, improving data accuracy and accessibility. Challenges like device ruggedness and user training are being overcome, making this increasingly standard. |
| **Regulatory "Sandbox" or Pilot Program**: A framework where regulators allow certain projects to use new techniques under relaxed rules to collect performance data (with oversight).<br>*Status:* Conceptual for remediation (the idea was floated to enable innovation without the full weight of regulations as a one-off trial). Regulators have not formally implemented this in Alberta, though similar concepts exist elsewhere (e.g., technology demonstration programs). | **"Approved Professional" Third-Party Review (BC Model)**: A system where certified professionals can review and vouch for regulatory closure submissions, which the government then issues with minimal further scrutiny.<br>*Deployed*: In BC's contaminated sites program, this approach expedites approvals by leveraging qualified persons. It was discussed as a successful practice that Alberta might consider to speed up routine closures. (This is more a process innovation than a tech tool, but it's a notable practice in use.) |

[30] See https://www.fulcrumapp.com/resources/data-sheet/migrating-from-survey123-to-fulcrum/

## APPENDIX 5 MeetGeek and Microsoft CoPilot Procedures to Develop Report Summaries

MeetGeek transcripts were created for each table for each session. MeetGeek was used to summarise the content for each session based on the combined transcripts for all tables. Microsoft CoPilot was then asked to summarise the combined MeetGeek summaries.

In addition, all the transcripts were combined into one document and Microsoft CoPilot was asked to summarise the transcripts.

For both summaries, the following prompts were created and used by Shane Patterson:

I would like the following:

A summary titled "Overall Workshop Summary" that contains the following:

- Using no more than 500 words I would like an overall summary of the workshop;
- The top 10 points made during the workshop;
- The top 10 opportunities identified during the workshop;
- The top 10 challenges identified during the workshop;
- The top 10 innovative technologies identified during the workshop; and,
- Bullets that could be used in a presentation to summarize the workshop.

For each of the 4 sessions, I would like summaries for each session using the following session titles:

- Session 1: Leveraging Innovation Throughout the Remediation Life Cycle
- Session 2: Sampling and Analysis: The Remediation Backbone
- Session 3: Opportunities for Increasing Technology-enabled Remediation
- Session 4: Opportunities to Improve Submissions: From Problem to Solution

For each session, I would like the following:

- Using no more than 500 words I would like an overall summary of all four sessions;
- The top 10 points made during the workshop;
- The top 10 opportunities identified during the workshop;
- The top 10 challenges identified during the workshop;
- The top 10 innovative technologies identified during the workshop; and,
- Bullets that could be used in a presentation to summarize the workshop.

## APPENDIX 6 Additional Insights

Microsoft CoPilot was used to gather information on specific topics that generated interest during the discussions.

### Appendix 6.1 Professional Responsibility, Accountability and Liability

***Professional Responsibility***

Participants consistently emphasized that professional responsibility ultimately rests with the regulated professional who signs off on remediation decisions and reports, regardless of tools used.

- Several speakers stressed that stamping a report carries full responsibility, whether the work was generated manually, by junior staff, or with AI-assisted tools. AI was widely viewed as *a tool*, not a substitute for professional judgment. If a professional signs, they are responsible for verifying, understanding, and defending the content.
- Consultants described an ethical obligation to look beyond short-term cost and convenience (e.g., dig-and-dump) and consider long-term environmental outcomes, including soil function, future land use, and intergenerational impacts. Landfilling was repeatedly described as *relocation rather than remediation*, implying that professionals have a duty to challenge its routine use when better solutions may exist.
- There was strong agreement that professionals should properly characterize and communicate actual risk, rather than defaulting to conservative actions that may not be justified by site conditions (e.g., unnecessary excavation for low-risk chloride or SAR impacts). Over-remediation was viewed as a failure of professional judgment, not prudence.

***Professional Accountability***

Accountability was discussed as shared but unevenly distributed across consultants, regulators, licensees, and landfill operators.

- Consultants noted that they are often held accountable for outcomes, while lacking authority over key drivers such as budget constraints, regulatory rigidity, and client risk tolerance. This tension pushes professionals toward "safe" conventional approaches, even when they believe better technical options exist.
- Regulators were seen as risk-averse gatekeepers, sometimes limiting modelling, adaptive management, or alternative remediation strategies even when conceptual site models indicate low risk. Participants acknowledged that regulators also face accountability pressures, particularly if innovative approaches fail post-closure.
- Participants highlighted that accountability gaps emerge over time, especially with landfilling. Once material is disposed of, responsibility is perceived to transfer, yet speakers argued that liability and environmental consequences do not truly disappear – only the visibility does.

### *Professional Liability*

Liability was one of the most explicit and strongly articulated themes.

- Multiple participants stated that landfilling creates long-term or perpetual liability, even if it appears cheaper in the short term. Monitoring, future remediation, and legacy risk were described as costs that are rarely priced into landfill decisions.
- A key concern was professional liability when adopting innovative or AI-enabled approaches. While professionals accepted that they remain liable for stamped work, uncertainty exists around whether errors and omissions insurance will respond if an issue arises from AI-assisted analysis or reporting. This uncertainty was identified as a growing barrier to innovation.
- Participants also pointed out that companies often fail to recognize environmental liabilities at their true value, unlike legal or accounting liabilities. This undervaluation diminishes the perceived worth of environmental professionals and incentivizes short-term fixes that defer, rather than resolve, liability.

### Overall Synthesis

Across the discussion, participants converged on a shared view that:

- **Responsibility** lies squarely with the signing professional to apply sound judgment, defend decisions, and resist unjustified defaults.
- **Accountability** is fragmented across the system, encouraging conservative behaviour and discouraging innovation.
- **Liability** is routinely misunderstood and underpriced, especially for landfilling and deferred remediation, creating long-term environmental and professional risk.

## Appendix 6.2 Policy and Legislation

Participants consistently felt that current policies and regulatory frameworks are a bigger barrier than technology itself. While regulations are well-intentioned and protective, they are widely seen as too rigid, slow, and risk-averse, unintentionally discouraging innovation and more sustainable remediation outcomes.

Key themes on policies and legislation

### *Regulatory Rigidity vs. Site-specific Risk*

Many comments criticized one-size-fits-all cleanup criteria (e.g., fixed Tier 1 standards) that do not adequately account for site context, exposure pathways, or actual risk to receptors.

Participants argued this leads to over-cleaning low-risk sites and wasted effort on minor exceedances, while diverting attention from genuinely high-risk situations.

There was strong support for risk-based and tiered closure approaches, where regulators focus on outcomes (risk reduction) rather than strict numerical compliance.

***Approval Processes Discourage Innovation***

Existing legislation and guidance were described as implicitly favouring conventional "dig-and-dump" approaches, because they are predictable and easy to approve under current rules.

Innovative options (e.g., in-situ treatment, leaving low-level contamination with controls, or soil reuse) face longer review times and higher approval uncertainty, even when risks are demonstrably low.

Participants noted there is no formal fast-track or sandbox mechanism in legislation to trial innovative remediation approaches under controlled conditions.

***Risk Aversion Embedded in Policy Culture***

Both regulators and regulated parties were described as structurally risk-averse, driven by legislation that penalizes failure more than it rewards better outcomes.

Annual budgeting cycles and compliance-driven legislation reinforce short-term thinking, making it difficult to justify longer-term, innovative remediation strategies.

Several comments suggested that legislation implicitly prioritizes defensibility over effectiveness, encouraging conservative decisions.

***Inconsistency Across Jurisdictions***

Participants highlighted significant inter-provincial differences in how legislation is applied, creating uncertainty for companies operating in multiple jurisdictions.

British Columbia's legislated Approved Professional model was frequently cited as more structured and rigorous, producing high-quality outcomes but with slower timelines and higher upfront costs.

Alberta's framework was described as more flexible but less predictable, placing greater responsibility on proponents and leading to uncertainty about what regulators will accept.

***Policy Misalignment with Sustainability Goals***

Current legislation was seen as misaligned with broader sustainability and ESG objectives, because it does not adequately account for lifecycle impacts, landfill capacity, greenhouse gas emissions, or long-term liabilities.

Participants suggested that policies continue to treat landfilling as an acceptable default, even though it merely transfers contamination rather than resolving it.

Several comments called for economic and policy levers (e.g., landfill restrictions, higher tipping fees, or incentives for treatment and reuse) to better align legislation with environmental outcomes.

### *Opportunities for Legislative Reform*

Strong support emerged for shifting legislation from prescriptive methods to performance-based outcomes, where any approach that meets risk and protection goals is acceptable.

Participants suggested formalizing:

- Risk-based screening and triage in legislation
- Conditional or monitored closures for low-risk residual contamination
- Greater use of qualified professionals to sign off routine cases
- Regulatory "sandboxes" or pilot provisions for innovative technologies

There was also interest in using legislation to enable better use of data and digital tools (e.g., automated checks, risk ranking), while keeping human judgment central.

## Appendix 6.3 Standards and Guidelines

Comments relative to standards and guidelines included:

### *Heavy Reliance on Prescriptive Standards (Tier 1 Criteria)*

The Workshop repeatedly highlighted that current remediation practice is dominated by rigid, prescriptive standards, particularly Alberta Tier 1 criteria, which are applied uniformly across sites regardless of context. Participants noted that these generic numerical standards often drive remediation decisions more than actual risk, reinforcing "dig-and-dump" approaches even when alternative solutions could achieve equivalent environmental protection.

### *Tension Between Rules-Based vs. Risk-Based Frameworks*

A major theme is the need to shift from rules-based standards to risk-based guidelines. Many contributors argued that standards should focus on risk to receptors (human, ecological, groundwater) rather than strict exceedances of generic criteria. The group strongly supported risk-based closure approaches, where contaminants may remain in place if they are stable, contained, and pose no unacceptable risk.

### *Limited Flexibility for Site-Specific Conditions*

Workshop participants noted that existing guidelines often fail to account for site-specific realities, such as:

- Natural background concentrations (e.g., metals or salinity)
- Remote sites with no receptors
- Unique land uses (e.g., native prairie)

Although tools and methods exist to address these situations, participants reported that guidelines are inconsistently applied or not always accepted, leading to prolonged reviews and conservative remediation outcomes.

### *Use of Site-Specific Guideline Adjustment Tools*

Risk-based calculation tools were discussed as mechanisms to work within existing guideline frameworks, including:

- Subsoil Salinity Tool (SST) for deriving site-specific chloride limits
- Formal risk assessments to justify alternative cleanup levels

These tools are widely used by practitioners and recognized by regulators, but submissions are still subject to close scrutiny, and acceptance depends heavily on data quality and professional judgment.

### *Inconsistency Across Jurisdictions*

The Workshop highlighted inter-provincial inconsistency in standards and guidelines as a major barrier. For example:

- British Columbia routinely applies risk-based closures and uses an Approved Professional (AP) model.
- Alberta is seen as more flexible procedurally but more reliant on fixed criteria.

This inconsistency makes it difficult for companies to scale innovative or risk-based approaches across regions and discourages broader adoption of alternative standards.

### *Approved Professional and Third-Party Review Models*

BC's Approved Professional (AP) system is repeatedly cited as an example of how standards can be upheld while improving efficiency. Under this model:

- Qualified third parties verify compliance with guidelines
- Regulators audit rather than re-review every detail

Participants suggested Alberta could adopt elements of this model to maintain standards while reducing bottlenecks, particularly for low-risk sites.

### *Balance Between Standardization and Professional Judgment*

There was broad agreement that some standardization is necessary (templates, clearer guidance, minimum expectations), especially for junior practitioners. However, participants cautioned against turning guidelines into a box-checking exercise. The preferred direction is:

- Clearer baseline standards and templates
- Continued allowance for professional judgment in complex or atypical cases.

### *Emerging Contaminants and Gaps in Standards*

Participants noted that standards for emerging contaminants (e.g., PFAS) are still evolving. Canada lacks fully developed national criteria in some cases, forcing practitioners to rely on draft guidelines or foreign benchmarks. This creates uncertainty, higher costs, and inconsistent decision-making across projects.

### *Specialized and Niche Guidelines*

Participants referenced specialized guidance documents (e.g., Native Prairie remediation guidelines) as positive examples of how standards can be adapted to protect sensitive land uses. These niche guidelines were viewed as effective but underutilized models for broader guideline evolution.

### *Call for Guideline Modernization*

Overall, the Workshop emphasized that current standards and guidelines are not fundamentally flawed, but they are:

- Too rigid
- Too slow to adapt
- Insufficiently aligned with risk-based decision-making

Modernization was framed as essential to enabling innovation while still maintaining environmental and public protection.

## Appendix 6.4 Costs and Economics

Comments relative to costs and economics included:

### *Cost as the Primary Decision Driver*

Participants repeatedly identified cost—not technical feasibility—as the dominant factor influencing remediation decisions. Lower-cost options are often selected even when they are not viewed as permanent or optimal remediation solutions.

### *Landfilling vs. Treatment Economics*

Landfilling is described as the cheapest option in Alberta, with a cited cost of approximately $40 per tonne, compared to about $300 per tonne in Korea. This cost differential strongly incentivizes landfill disposal over treatment-based remediation in Alberta.

A specific comparison was discussed where treatment would have cost approximately $14 M, while landfilling the same material cost approximately $4 M for about 27,000 $m^3$ of contaminated soil. This example was used to illustrate why landfill disposal is frequently chosen on economic grounds.

### *Cost of Treatment Technologies*

Bioremediation was discussed as a lower-cost alternative to dig-and-dump in some cases. One example cited bioremediation using alfalfa pellets, which reportedly cost approximately 25% of the cost of traditional dig-and-dump remediation.

### *Field Tools and Operational Cost Savings*

Use of in-field analytical tools (e.g., hydrocarbon and salt screening tools) was reported to provide significant daily cost savings, particularly on remote sites. One tool reportedly reduced lab turnaround delays and saved approximately $10,000 to $15,000 per day by enabling faster excavation decisions.

### *AI, Data, and Efficiency Economics*

AI and data-driven tools were consistently framed as cost-reduction and efficiency tools, not replacements for professional judgment.

Economic benefits discussed included:

- Reduced reporting and administrative costs through automated data compilation, visualization, and report drafting.
- More efficient site characterization, potentially reducing over-sampling, unnecessary excavation, and conservative "worst-case" remediation volumes.
- Risk-based prioritization, allowing resources to be focused on high-risk sites rather than expended on low-risk exceedances.

### *Regulatory and Risk-related Cost Impacts*

Regulatory risk aversion was described as a significant cost driver. Conservative requirements can lead to redundant sampling, over-remediation, and prolonged project timelines, increasing total project costs.

Lack of regulatory acceptance for new technologies increases financial risk, discouraging investment in potentially lower-cost remediation approaches.

Short budgeting cycles and uncertainty around regulator acceptance were cited as economic barriers to piloting or scaling innovative remediation technologies.

### *Market and Pricing Pressures*

Some participants noted downward pressure on consulting prices due to automation and standardization (e.g., very low-cost Phase I assessments).

While automation can lower costs and improve efficiency, there was concern that commoditization may reduce margins, potentially limiting investment in higher-quality or innovative remediation solutions.

### *Overall Economic Takeaways from the Session*

Cost differentials strongly favour landfilling over treatment under current Alberta conditions.

Lower-cost treatment and field technologies exist, but adoption is constrained by regulatory acceptance, risk aversion, and uncertainty.

Operational efficiencies (field screening, AI-assisted workflows) can yield meaningful cost savings, especially on remote or large sites.

Economic decisions are closely tied to regulatory frameworks, with conservative requirements often driving higher total remediation costs rather than risk-based optimization.

## Appendix 6.5 Education and Training Needs and Opportunities

### Education and Training Needs

#### *Lifecycle Understanding for Early-Career Staff*

Participants repeatedly emphasized that many junior or "green" staff lack a holistic understanding of the remediation lifecycle. New practitioners often focus narrowly on their assigned task (e.g., Phase I or fieldwork) without understanding downstream implications for remediation, closure, or long-term liability. This gap leads to inefficiencies, repeat site visits, and higher overall costs.

***Need***: Training that clearly connects Phase I, Phase II, remediation, risk assessment, and closure as a single integrated process rather than isolated steps.

#### *Knowledge Transfer from an Aging Workforce*

There was strong concern about loss of institutional knowledge as experienced professionals retire. Participants noted that decades of practical remediation and soils expertise are leaving the industry faster than they are being replaced.

***Need***: Structured approaches to capture and transfer practical knowledge (decision logic, judgment calls, lessons learned) that are not well documented in guidelines.

#### *Shortage of Soil Science Expertise*

Multiple participants highlighted a decline in formal soils training among new graduates. Many incoming resumes are from biology, wildlife, or conservation backgrounds, with limited grounding in soil science, reclamation, or contamination behaviour in soils.

***Need***: Targeted education in soil science fundamentals, reclamation soils, salinity, hydrocarbons, and soil health – either through university programs or post-graduate professional training.

#### *Inconsistent Training Across Firms*

Training quality and content were described as highly variable between consulting firms, with each company developing its own internal approach. As a result, practitioners with similar experience levels may have very different competencies.

***Need***: More consistent, industry-recognized training frameworks or baseline competencies for remediation practitioners.

#### *Risk-Based Thinking and Conceptual Site Models (CSMs)*

Participants noted that practitioners often move too quickly to remedial action (e.g., dig and dump) without fully understanding risk pathways, receptors, and conceptual site models. This reflects a training gap in applying risk-based decision-making rather than checklist compliance.

***Need***: Training that strengthens skills in CSM development, risk assessment, and justification of alternative remediation approaches.

### *Responsible Use of AI and Automation*

While AI tools are increasingly used for reporting, data management, and summarization, participants expressed concern that over-reliance on AI could undermine learning, especially for junior staff. There was recognition that AI does not replace professional judgment and accountability.

***Need***: Training on how to use AI as a support tool while still developing core technical, analytical, and writing skills.

## Education and Training Opportunities

### *AI-Enabled Learning and Onboarding*

Participants identified an opportunity to use AI and digital tools to enhance education, not just productivity. AI could support interactive learning, scenario-based training, and explanations of remediation workflows for new staff.

***Opportunity***: Develop AI-supported training modules that explain remediation life cycles, decision points, and common pitfalls.

### *Standardized SOPs and Training Modules*

There was interest in using technology to support standard operating procedures (SOPs) and consistent onboarding across projects and organizations.

***Opportunity***: Industry-wide or consortium-based SOPs and training content that firms can adapt, improving baseline competency while preserving flexibility.

### *Virtual and Experiential Training (VR / Simulations)*

Examples were discussed where virtual reality or site walkthrough tools were used to simulate field conditions and decision-making. These were seen as effective for introducing staff to complex sites before field deployment.

***Opportunity***: Expand use of VR, digital twins, or interactive site simulations for field training and hazard awareness.

### *Peer-to-Peer Learning and Mentorship*

Participants emphasized the value of mentorship, peer discussion, and shared experience, particularly where proprietary concerns limit data sharing.

***Opportunity***: Structured mentorship programs, peer exchanges, and facilitated workshops that allow experienced practitioners to teach judgment-based skills.

### *Earlier Engagement with Education Systems*

There was discussion about engaging high schools and universities to raise awareness of soil science and remediation as career paths, countering the current emphasis on conservation-only streams.

***Opportunity***: Outreach, guest lectures, and partnerships with post-secondary institutions to rebuild the pipeline of soils and reclamation specialists.

### *Training for Regulators and Industry Alignment*

Implicit in the discussion was the need for shared understanding between practitioners and regulators, particularly around risk-based decisions, modelling, and innovative remediation approaches.

***Opportunity***: Joint training sessions or workshops involving regulators, consultants, and operators to improve alignment and confidence in alternative approaches.