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Technical Impracticability Waivers: An underutilized tool for managing sediment sites

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A Superfund Record of Decision (ROD) for a sediment site documents the cleanup levels (CULs) directing the sediment cleanup, and it lays out the long-term objectives aimed at protecting sensitive receptors and restoring waterways to support fishing and recreation. Parties responsible for remedial design often struggle with designing sediment remedies that efficiently meet low-level CULs when incoming sediment sources and natural conditions control the expected cleanliness after remediation.

CULs are established for various chemicals in multiple media identified through a combination of the following:

- Applicable or relevant and appropriate requirements (ARARs)—promulgated standards in federal and state regulations.
- Risk-based goals—calculated through risk assessments that use assumed levels of exposure for humans and animals over certain periods of time to predict safe concentrations of chemicals in fish tissue and sediment.
- Background conditions—when ARARs and risk-based goals are lower than levels in the environment unrelated to the Superfund site, the CUL can be adjusted to reflect the background levels.
- Analytical limits—the CULs should not be lower than what a laboratory can measure in a sample. So, a risk-based goal can be adjusted upward to a detectable level.

CULs are usually set for multiple groups of chemicals including:

A. Legacy industrial chemicals with focused areas of higher concentrations in sediment (pink in Figure 1) surrounded by mid- to lower-level concentrations (peach, green). Cleanup can address the mid- and higher-level areas, but might not achieve very low-concentration goals calculated through risk assessments (dark blue) if the chemicals continually move into the site from diffuse, urban sources (e.g., stormwater runoff from highways represented by the aqua and green gradation in Figure 1).

B. Naturally-occurring chemicals, like metals, that can have some urban sources, but are also widely present due to geological conditions. Although Group B chemicals are naturally occurring, cleanup criteria for these chemicals can be developed through risk assessments. Such calculations might identify risk from natural conditions, and risk-based CULs would be unattainable if they are lower than geologically influenced conditions.

Figure 1: the colors represent concentrations of a single Group A analyte in surface sediment. Pink/ peach indicates a higher-concentration area.

CULs are to be met after active remediation and/or a period of natural recovery over an exposure area (e.g., areas over which sport fish typically swim). But what if the CULs established in a ROD fail to account for natural conditions and are not adjusted upward sufficiently to an achievable background-based level? As more information comes to light after a ROD is issued, such as further understanding of natural background sources, it can be common for EPA to revisit the criteria set in a ROD. EPA documents such revisions in a ROD amendment, an erratum, or an explanation of significant differences document. Another approach lies with performing parties making the case to waive certain CULs defined in a ROD: this is, to request an ARAR Waiver for Technical Impracticability.

Technical Impracticability

We strive to design sediment remedies that are technically achievable over a reasonable course of action and, ideally, in a manner that maintains the waterway's function and does not cause more harm than benefit. For Group A type chemicals, this can mean addressing small, focused areas having the highest concentrations such that an average concentration after cleanup meets the CUL, as shown in Figure 2—a reasonable effort and cost yielding maximum benefit.

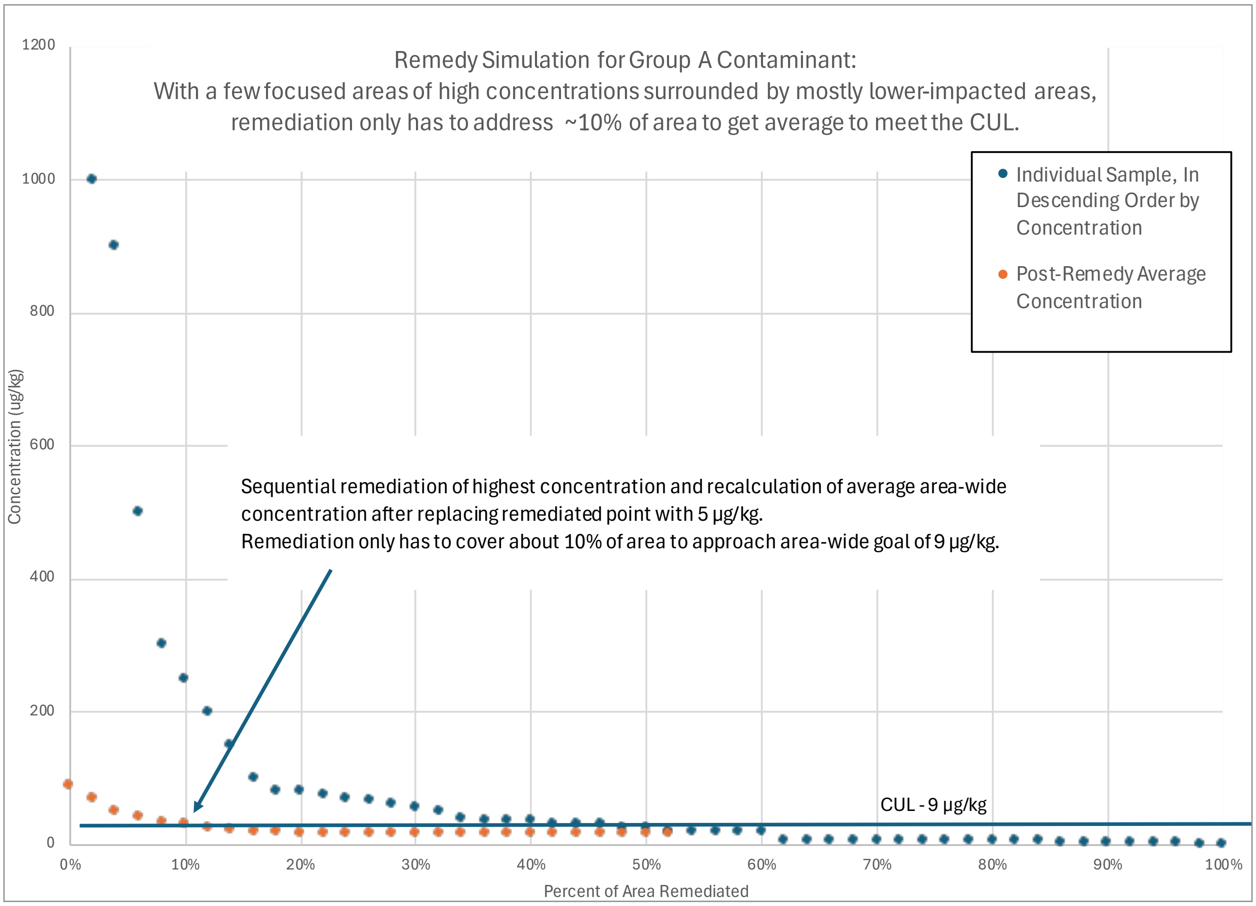

Figure 2: Remedy simulation for Group A contaminant

Sediment remediation should be technically feasible and use resources wisely. We usually identify relatively high concentrations of legacy industrial chemicals (yellow area for Group A chemicals in Figure 3) to indicate where their cleanup would lead to area-wide lower concentrations of all chemicals of concern (overlap of Group A and Group B chemicals in yellow area in Figure 3).

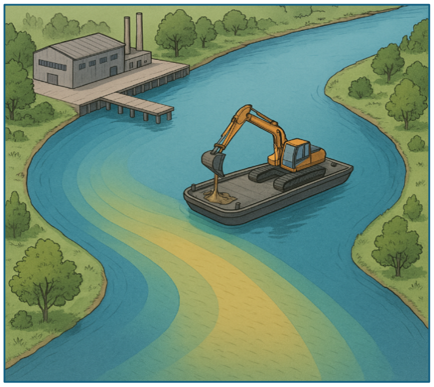

Figure 3: The colors represent concentrations of a single Group B analyte in surface sediment. Yellow indicates area also elevated for Group A chemical

Group B Distribution and Remediation Plan

- enrichment from an anthropogenic source to be dredged to target because colocaed with Group A high concentrations
- range of natural levels; should not dredge this area because sediment will re-equilibrate after dredging to these levels
- long term cleanup goal set by a risk-based calculation or set by a too-low understanding of natural background. not shown on the figure because not present before remediation cannot meet level lower than existing anywhere in site or upstream

For Group B chemicals, remediated areas might immediately be very low in concentration (e.g., matching the concentration in a coarse sand placed over the dredge surface), but the concentrations in the sediment will eventually re-equilibrate to the surrounding natural/regional concentrations (yellow-green to blue in Figure 3). If the goal is to achieve a CUL that is lower than background for a Group B chemical (navy blue in Figure 3 legend) immediately after construction, one would have to dredge or cap a very large area (or an impossibly large area). That is, there may not be an area large enough to dredge or cap that would ever result in the post-remedy sediment condition meeting a dark blue level (Figure 3).

Figure 4 shows an example of how, for a Group B chemical with concentrations close to background levels, a very large area would need to be remediated to achieve an average concentration immediately after construction at the CUL. In Figure 4, 60 percent of the study area needs to be remediated to achieve the CUL, because there are no discrete hot spots as there are for Group A chemicals.

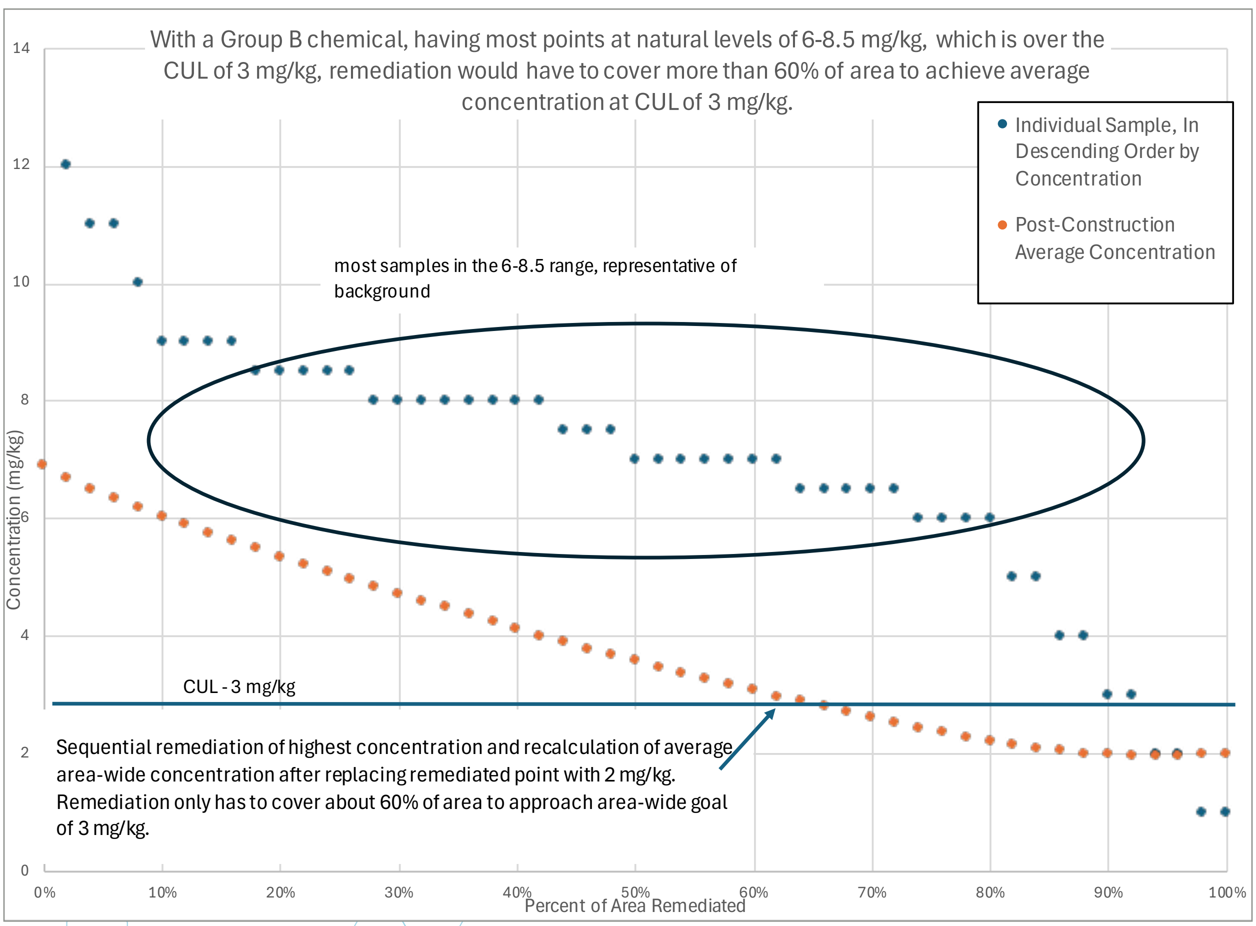

Figure 4: Area requiring remediation for Group B chemical with concentrations near background

Attempting to dredge that much sediment might not be technically feasible for a number of reasons:

- Deep and wide dredge cuts might be structurally unstable.
- Dredging equipment cannot reach below wharfs or very close to steep banks without undermining them.
- Construction work windows (fish windows) may be too short to accommodate the many weeks of dredging duration.
- The process of moving this volume of sediment from the river, to the land, to the landfill is logistically challenging and resource intensive (requiring significant fuel and resulting in unnecessary emissions).
- The supply of dredge equipment cannot meet the demand.
- Harbor traffic cannot be disrupted over a period sufficient to remove the large volume.
- The removal volume would be so great that the riverbed is essentially denuded.

Further, all of this remediation might not achieve the desired goal because the area will eventually reequilibrate to the surrounding, background conditions regardless of how much area is remediated. In Figure 3, this means that after remediation, the area becomes yellow-green and aqua again despite the dark blue goal.

Thus, the CUL (the goal) is technically impracticable.

We also seek to design remedial actions that consider green and sustainable practices. Actions in conflict with green principles include excessive fuel use and emissions for long-range transport of material out of the waterway and to a landfill, particularly when this material is not truly polluted (i.e., if the remedy is due to Group B chemicals in the green-blue range in Figure 3). Similarly, building a sediment cap for Group B chemicals to control for natural geological conditions in sediment porewater, if technically feasible, could require a lot of material dug up from a quarry (e.g., sand) and a lot of man-made amendments (e.g., activated carbon).

Therefore, the additional remediation extending beyond the yellow indicator in Figure 3 targets levels that are not sustainable over the long term. Besides being technically impracticable to clean up this much sediment, due to the reasons above, the excess construction imparts high resource and financial costs in exchange for no added benefit.

Is There Precedent?

The National Contingency Plan provides for the following types of waivers of ROD-defined ARARs:

- **Interim Measures Waiver:** The alternative is an interim measure and will become folded into a final remedial action that is expected to attain the federal and/or state ARARs.
- **Greater Risk to Health and the Environment Waiver:** Compliance with the requirement will result in greater risk to human health and the environment than other alternatives.
- **Equivalent Standard of Performance Waiver:** The alternative will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach.
- **Fund-Balancing Waiver:** For EPA-funded response actions only, an alternative that attains the ARAR will not provide a balance between the need for protection of human health and the environment at the site and the availability of fund monies to respond to other sites that may present a threat to human health and the environment.
- **Technical Impracticability Waiver [TI Waiver]:** Compliance with the requirement is technically impracticable from an engineering perspective, so an alternative remedial strategy is proposed. That strategy can be the use of a higher, more attainable, CUL.

EPA developed guidance in 1993 outlining the TI waiver process specific to groundwater restoration (USEPA 1993). However, over the following couple of decades, EPA issued only 91 waivers across 85 Superfund sites nationwide, with a precipitous drop in the use of TI waivers since 2011.

There may be no direct precedent for the use of a TI waiver for sediment Superfund sites because all of the waivers EPA has granted and published online are related to groundwater and surface water sites. Most often drinking water-related standards have been waived, typically because the groundwater under consideration is not, and will not be in the future, used as a source of drinking water; so a lack-of-exposure rationale supports the waiver. In approved TI waivers, engineering factors presenting technical impracticability to implement a remedial action include complex geology and hydrogeology, presence of contaminants with unique properties, and a drawn-out anticipated timeframe to operate a treatment system before the conservative goals are achieved. Metals were the contaminant of interest in roughly half of the approved TI waivers.

Conclusions

The precedent of metals-related TI waivers for groundwater provides an opportunity for adapting the concept to sediment sites, where cleanup criteria have been codified for background-sourced and naturally occurring metals (referred to as Group B chemicals in this article). Using the TI waiver as a tool to focus sediment cleanups away from diffuse inputs and more squarely on detrimental concentrations of legacy pollutants (Group A chemicals in this article) can streamline remedial designs and monitoring programs, bringing resolution of an impacted sediment site closer to the finish line.

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Unlocking the Future of Environmental Monitoring: Environmental DNA as a Tool for Biological Characterization and Site Management (Part One of a Two-Part Series)

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Biological monitoring is a common requirement in many environmental site management contexts, such as contaminated site assessment, ecological risk assessment, regulatory permitting, and ecological restoration. Traditional biological monitoring methods involve time- and labor-intensive field surveys and species identification by trained biologists.

Over the past decade, an innovative new analytical tool for biological monitoring has emerged: **environmental DNA (eDNA)**. This noninvasive sampling method can provide robust community data to supplement traditional survey methods and to provide an additional line of evidence to assess biodiversity, monitor ecological health and recovery, and efficiently manage environmental and greenfield sites.

This article is Part 1 of Integral's two-part series on the cutting-edge applications of eDNA. This installment provides an introduction to eDNA and explores the advantages and challenges of eDNA analysis for site management applications. Our future installment will highlight how eDNA can be a useful component of the sediment practitioner's toolbox across a range of project types.

Traditional Biological Assessments: Strengths and Limitations

Biological assessments can establish baseline conditions at a site, demonstrate impacts of cleanup or management actions, and/or show changes in the ecological community over time. Example applications of such surveys include:

- Characterization of benthic invertebrate or fish communities during the remedial investigation and risk assessment phases under Superfund and state cleanup programs
- Assessment of marine mammal populations near offshore development projects
- Monitoring of vegetation for wetland restoration projects
- Analysis of benthic invertebrate communities for National Pollutant Discharge Elimination System discharge permit monitoring
- Early detection of the presence of invasive species before their establishment—saving significant time and resources at eradication once established.

In all instances, traditional methods involve direct observation and capture of organisms, followed by field or laboratory-based taxonomic identification.

The information collected through these survey methods provides quantitative data regarding populations and supports calculation of ecological metrics that have long been relied upon to characterize communities. While effective and part of the lexicon, these methods:

- Are labor-intensive, time consuming, and costly
- Require detailed subject matter expertise, expertise that is waning in supply as classical taxonomists retire and are not replaced
- Are potentially limited in their ability to detect rare or cryptic species
- Are limited by the ability to catch certain species and members of their subpopulations (age class, sex)
- Are dependent on seasonal and environmental conditions
- May be injurious or lethal to targeted individuals
- May be injurious or lethal to nontarget individuals (e.g., trawling bycatch)
- Can be biased by survey methods, locations, and researchers' ability to identify species.

These limitations have prompted the search for more efficient, comprehensive, more objective, and less intrusive alternatives—leading to the rise of eDNA.

What is eDNA?

Environmental DNA refers to genetic material shed by organisms into their surroundings through skin cells, mucus, feces, or other biological processes. This DNA can be collected from environmental media, such as water or sediment, as well as from tree canopies and from vegetation—basically from anything that may have been a receptor to genetic material. The media are then processed to collect genetic material and analyzed to determine which species are or were recently present in an environment.

The process typically involves:

1. Sample collection (e.g., filtering water or collecting sediment from a water body)
2. DNA extraction and amplification using polymerase chain reaction (PCR) techniques
3. High-throughput DNA sequencing systems (aka Next Generation Sequencing or NGS) and bioinformatics to match DNA fragments to known species libraries.

There are two general approaches that may be employed for species identification: targeted analysis for specific species or metabarcoding to assess groups of species. For target species identification, a DNA sequence (or "primer") specific to the species of interest is amplified using quantitative PCR (qPCR) to confirm presence/absence of the species. In some instances, validated qPCR assays may be able to provide some insight on abundance, as well. Metabarcoding uses a universal primer (i.e., a sequence of DNA that is consistent across a group of organisms) to amplify DNA for many species using one reaction.

With either method, the best results are achieved with newly emerging high-throughput sequencing systems and sample processing technologies that allow for millions to billions of "reads" of that DNA sequence of interest. These systems provide deeper sequencing coverage, meaning more reads are obtained for a given region of a genome, leading to more accurate variant detection and the ability to detect species of interest when limited genetic material is present in the sample. An abundance of information increases the statistical power of the bioinformatic analyses and enables questions to be answered with greater sensitivity and precision.

After sequencing, the results enter the bioinformatics phase of the process and are compared to a database to determine which species are present. Genetic libraries are growing in both depth and breadth—allowing genomic approaches to be more widely implemented—for example, the GEANS project (Genetic Tools for Ecosystem Health Assessment in the North Sea Region) has recently released a curated DNA barcode library for common macroinvertebrates of soft bottom habitats, which represents 29 percent of the known North Sea macrobenthos species (Christodoulou et al. 2025). Bioinformatic computing systems, the application of AI, and other continuous improvements in genomic technology are increasing the depth and breadth of barcode libraries at an incredibly rapid pace, thus the abilities of eDNA are continually improving.

Advantages of eDNA

Incorporation of eDNA analysis as a part of the modern site assessment toolkit can provide several advantages for any project where biological monitoring is being implemented, such as:

- **Cost-Effective:** Requires fewer personnel and less field time
- **Autonomous:** New remote sampling systems are being deployed
- **Scalable:** Enables more frequent and widespread sampling
- **Straightforward:** Samples can be collected with minimal training
- **Non-invasive:** Reduces harm to organisms and habitats
- **Greater Sensitivity:** Detects species that are rare, elusive, or present in low abundance
- **Complementary:** Enhances traditional methods rather than replacing them.

Studies comparing eDNA with traditional trawl and benthic surveys (e.g., Stoeckel et al. 2021; Ji et al. 2023) show that eDNA often identifies more species and provides a broader picture of community composition. A study in Swiss streams (Brantschen et al. 2021) demonstrated strong alignment between eDNA and traditional biotic indices, supporting its regulatory use.

Challenges and Considerations

Despite its promise, broader acceptance of eDNA is not without hurdles, which include:

- **Regulatory Acceptance:** Although many regulatory frameworks are still built around traditional methods, some agencies at state and federal levels in the U.S. and abroad are encouraging adoption of eDNA as a tool for environmental management. For example, the National Science & Technology Council published its Aquatic Environmental DNA Strategy, which recommends a "nationwide eDNA network to inform decisions that promote resilient ecosystems" (NSTC 2024). This acceptance is expected to grow over time. But broader adoption of eDNA will require:
  - Education of regulators and stakeholders
  - Demonstration of equivalency to or superiority over existing methods
  - Integration into existing biotic indices and assessment protocols.
- **Standardization:** Efforts to develop best practices and standards across the industry are well underway (e.g., by the International Standards Organization and industry groups such as IOGP[1] and others[2]). To ensure consistency and reliability, the field needs:
  - Standardized sampling and analysis protocols
  - Quality assurance and control measures
  - Increased laboratory capacity to provide results in a timely fashion as use increases.
- **Interpretation of Results:** eDNA data can be influenced by a range of environmental factors, species-specific considerations, and methodological differences. Understanding these nuances is essential for developing suitable sampling approaches and data quality objectives, accurate data interpretation, and application to decision-making.

The Path Forward

The integration of eDNA into environmental monitoring represents a paradigm shift. As methods become more refined and regulatory frameworks evolve, eDNA is poised to become a mainstream tool in site assessment and ecological management.

To fully realize the potential of eDNA, the environmental science community must:

- Continue validating eDNA against traditional methods
- Develop robust standards and best practices
- Foster collaboration between researchers, regulators, and industry
- Continue to build genetic libraries validated against traditional assessments of species type
- Promote genomic methods as a complementary and efficient way to gain comprehensive ecological and biological data.

Stay tuned for Part 2 in this series, which will present case studies of eDNA applications within Superfund sites and greenfield applications.

[1] International Association of Oil and Gas Producers https://www.iogp-edna.org/publications/

[2] For example, International eDNA Standardization Task Force https://iestf.global/, iTrackeDNA https://itrackdna.ca/, and the Centre for Environmental Genomics Applications https://www.cegacanada.com/

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Mr. Andrew Halmstad is an engineer with 7 years of consulting experience focusing on environmental remediation and cost allocation of contaminated sediments, groundwater, and soils. His specific skills include reviewing and summarizing results of ongoing environmental investigations, supporting source control and remedial design activities, and data analysis for site characterization and remedial activities. Mr. Halmstad has supported and led numerous field operations, including site investigations, in situ remedial treatment application, aquifer testing, remediation system operations maintenance and monitoring, and sampling of soil, groundwater, and stormwater. He also has experience planning, managing, and conducting environmental investigations; analyzing remedial alternatives; conducting feasibility studies; and providing oversight of remedial measures.

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Dr. Chris Sinton uses his broad, multidisciplinary background to help clients rapidly and accurately assess and solve a range of environmental issues. He has applied his extensive experience in project management and practical laboratory and fieldwork to remediation projects, site assessments, litigation support, and cost allocation. Dr. Sinton has particular expertise in the glass and ceramic industry and sustainability of materials and energy. He works closely with clients and counsel to develop data-driven solutions for complex, multifaceted projects.

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Ms. Nicole Ott is an environmental scientist with more than 20 years of consulting experience, working with attorneys, industrial clients, and municipalities. Her clients rely on her focused preparation of sediment characterization, remediation, and allocation/source deliverables. Critical to much of this work is synthesizing historical industrial practices to develop allocation strategies and to understand contaminant sources and pathways. Working closely with counsel, she leads teams to weave together forensic evaluations, sediment transport studies, and historical research, taking a science-based approach to seek novel solutions. Collaborating with multidisciplinary project teams, Ms. Ott consistently delivers high-quality reports and presentations her clients can understand and use. These communications lead to an amenable path forward among clients, regulators, and other stakeholders.

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Dr. Jennifer L. Wollenberg is a multidisciplinary expert in the environmental sciences, who leverages her skills to help clients understand and manage business risks and opportunities in relation to natural resources. Dr. Wollenberg has spent more than 20 years characterizing the physical, chemical, and biological conditions at commercial and industrial sites to help clients better understand the environmental footprint of their operations, including potential impacts to natural resources. She works with corporate decision-makers to develop environmental management strategies that integrate with other aspects of their compliance programming and environmental, social, and corporate governance (ESG) reporting.

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Mr. Daniel Doolittle is a broadly trained marine scientist and senior program manager with more than 25 years of industry, government, academic research, and consulting experience. He specializes in the marine geological, geochemical, and environmental fields and has specific core competencies in the following areas:

- Environmental and exploration consultancy services to the offshore wind, oil and gas, and renewable energy industries
- Expertise in carbonate sedimentology, hydrocarbon seeps exploration, environmental baseline studies, seafloor habitat mapping, and technology development for seafloor remote sensing sensors and systems
- Strategic market and business development, program management, and all phases of project delivery.

Mr. Doolittle's extensive field experience includes projects in multiple frontier offshore basins, remote regions, and most global oceans, including high latitude waters from Antarctica to the Arctic.

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Ms. Sadie McGarvey has 12 years of professional experience as a field biologist and regulatory specialist, working in a variety of habitats and municipalities. She has a wide range of experience in biological fieldwork, regulatory compliance, and environmental permitting. Her professional experience includes California Environmental Quality Act (CEQA) level site assessments and reporting, due diligence reporting, regulatory compliance support for various development, reclamation, repair, transportation, and utilities projects throughout Northern California, construction compliance monitoring, vegetation and hydrology monitoring, vegetation mapping, wetland delineations and habitat assessments, and special-status species surveys and research. Ms. McGarvey assists clients with navigating environmental regulations and obtaining regulatory authorizations from the U.S. Army Corps of Engineers (USACE), state and regional Water Quality Control Boards, California Department of Fish and Wildlife (CDFW), and U.S. Fish and Wildlife Service (USFWS). She ensures projects meet permitting and construction milestones while staying in compliance with regulatory authorizations and applicable laws.

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