Processes, Assessment and Remediation of Contaminated Sediments

Danny D. Reible
Editor

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SERDP and ESTCP Remediation Technology Monograph Series
Series Editor: C. Herb Ward, Rice University

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SERDP and ESTCP have joined to facilitate the development of a series of monographs on remediation technology written by leading experts in each subject area. This volume is intended to help engineers and scientists better understand contaminated sediment sites and identify and design remedial approaches that are more efficient and effective. Volumes previously published in this series include:

- *In Situ* Bioremediation of Perchlorate in Groundwater
- *In Situ* Remediation of Chlorinated Solvent Plumes
- *In Situ* Chemical Oxidation for Groundwater Remediation
- Delivery and Mixing in the Subsurface: Processes and Design Principles for *In Situ* Remediation
- Bioaugmentation for Groundwater Remediation

The following volume is planned for publication in the near future:

- Chlorinated Solvent Source Zone Remediation

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Preface

In the late 1970s and early 1980s, our nation began to grapple with the legacy of past disposal practices for toxic chemicals. With the passage in 1980 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, it became the law of the land to remediate these sites. The U.S. Department of Defense (DoD), the nation's largest industrial organization, also recognized that it too had a legacy of contaminated sites. Historic operations at Army, Navy, Air Force, and Marine Corps facilities, ranges, manufacturing sites, shipyards, and depots had resulted in widespread contamination of soil, groundwater, and sediment. While Superfund began in 1980 to focus on remediation of heavily contaminated sites largely abandoned or neglected by the private sector, the DoD had already initiated its Installation Restoration Program in the mid-1970s. In 1984, the DoD began the Defense Environmental Restoration Program (DERP) for contaminated site assessment and remediation. Two years later, the U.S. Congress codified the DERP and directed the Secretary of Defense to carry out a concurrent program of research, development, and demonstration of innovative remediation technologies.

As chronicled in the 1994 National Research Council report, "Ranking Hazardous-Waste Sites for Remedial Action," our early estimates on the cost and suitability of existing technologies for cleaning up contaminated sites were wildly optimistic. Original estimates, in 1980, projected an average Superfund cleanup cost of a mere $3.6 million per site and assumed only around 400 sites would require remediation. The DoD's early estimates of the cost to clean up its contaminated sites were also optimistic. In 1985, the DoD estimated the cleanup of its contaminated sites would cost from $5 billion to $10 billion, assuming 400–800 potential sites. A decade later, after an investment of over $12 billion on environmental restoration, the cost to complete estimates had grown to over $20 billion and the number of sites had increased to over 20,000. By 2007, after spending over $20 billion in the previous decade, the estimated cost to address the DoD's known liability for traditional cleanup (not including the munitions response program for unexploded ordnance) was still over $13 billion. Why did we underestimate the costs of cleaning up contaminated sites? All of these estimates were made with the tacit assumption that existing, off-the-shelf remedial technology was adequate to accomplish the task, that we had the scientific and engineering knowledge and tools to remediate these sites, and that we knew the full scope of chemicals of concern.

However, it was soon and painfully realized that the technology needed to address the more recalcitrant environmental contamination problems, such as fuels and chlorinated solvents in groundwater and dense nonaqueous phase liquids (DNAPLs) in the subsurface, was seriously lacking. In 1994, in the "Alternatives for Ground Water Cleanup" document, the National Research Council clearly showed that as a nation we had been conducting a failed 15-year experiment to clean up our nation's groundwater and that the default technology, pump-and-treat, was often ineffective at remediating contaminated aquifers. The answer for the DoD was clear. The DoD needed better technologies to clean up its contaminated sites and better technologies could only arise through a better scientific and engineering understanding of the subsurface and the associated chemical, physical, and biological processes. Two DoD organizations were given responsibility for initiating new research, development, and demonstrations to obtain the technologies needed for cost-effective remediation of facilities across the DoD: the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP).

SERDP was established by the Defense Authorization Act of 1991 as a partnership of the DoD, the U.S. Department of Energy, and the U.S. Environmental Protection Agency; its mission is "to address environmental matters of concern to the Department of Defense and the Department of Energy through support of basic and applied research and development of technologies that can enhance the capabilities of the departments to meet their environmental obligations." SERDP was created with a vision of bringing the capabilities and assets of the nation to bear on the environmental challenges faced by the DoD. As such, SERDP is the DoD's environmental research and development program. To address the highest-priority issues confronting the Army, Navy, Air Force, and Marine Corps, SERDP focuses on cross-service requirements and pursues high-risk and high-payoff solutions to the DoD's most intractable environmental problems. SERDP's charter permits investment across the broad spectrum of research and development, from basic research through applied research and exploratory development. SERDP invests with a philosophy that all research, whether basic or applied, when focused on the critical technical issues, can impact environmental operations in the near term.

A DoD partner organization, ESTCP, was established in 1995 as the DoD's environmental technology demonstration and validation program. ESTCP's goal is to identify, demonstrate, and transfer technologies that address the DoD's highest-priority environmental requirements. The program promotes innovative, cost-effective environmental technologies through demonstrations at DoD facilities and sites. These technologies provide a large return on investment through improved efficiency, reduced liability, and direct cost savings. The current cost and impact on DoD operations of environmental compliance are significant. Innovative technologies are reducing both the cost of environmental remediation and compliance and the impact of DoD operations on the environment, while enhancing military readiness. ESTCP's strategy is to select laboratory-proven technologies with potential broad DoD application and use DoD facilities as test beds. By supporting rigorous test and evaluation of innovative environmental technologies, ESTCP provides validated cost and performance information. Through these tests, new technologies gain end-user and regulatory acceptance.

In the 18–22 years since SERDP and ESTCP were formed, much progress has been made in the development of innovative and more cost-effective environmental remediation technology. Since then, recalcitrant environmental contamination problems for which little or no effective technology had been available are now tractable. However, we understand that newly developed technologies will not be broadly used in government or industry unless the consulting engineering community has the knowledge and experience needed to design, cost, market, and apply them.

To help accomplish the needed technology transfer, SERDP and ESTCP have facilitated the development of a series of monographs on remediation technology written by leading experts in each subject area. Each volume is designed to provide the background in process design and engineering needed by professionals who have advanced training and 5 or more years of experience. The first volume in this series, *In Situ Bioremediation of Perchlorate in Groundwater*, meets a critical need for state-of-the-technology guidance on perchlorate remediation. The second volume, *In Situ Remediation of Chlorinated Solvent Plumes*, addresses the diverse physical, chemical, and biological technologies currently in use to treat what has become one of the most recalcitrant contamination problems in the developed world. The third volume, *In Situ Chemical Oxidation for Groundwater Remediation*, provides comprehensive, up-to-date descriptions of the principles and practices of *in situ* chemical oxidation for groundwater remediation based on a decade of intensive research, development, and demonstration. The fourth volume, *Delivery and Mixing in the Subsurface: Processes and Design Principles for In Situ Remediation*, describes the principles of chemical delivery and mixing systems and their design and implementation for effective *in situ* remediation. The fifth volume, *Bioaugmentation for Groundwater Remediation*, covers the history, current status, and the exciting future prospects for deliberately adding bacteria and other agents to treat contaminated groundwater.

The purpose of this volume, *Processes, Assessment and Remediation of Contaminated Sediments*, is to help engineers and scientists better understand contaminated sediment sites and identify and design remedial approaches that are more efficient and effective. Contaminated sediment management is a difficult and costly exercise that is rarely addressed with easily identified and implemented remedies. It is hoped that this book can help identify and implement management approaches that provide an optimal, if not entirely satisfactory, solution to sediment contaminant problems.

In order to accomplish our goal, this volume contains a variety of topics needed to understand, assess, and manage contaminated sediment sites:

- An introduction to contaminated sediment management that summarizes the trade-offs between natural attenuation, containment, and active removal (Chapter 1).
- A series of chapters describing key sediment processes that separate sediments from contaminated soil sites and make understanding sediment processes difficult. These include:
  - An introduction to the processes that are uniquely associated with contaminated sediment sites including sediment resuspension, groundwater upwelling, hyporheic exchange, and bioturbation (Chapter 2).
  - A chapter detailing current understanding of sediment erosion and transport and how these processes are modeled (Chapter 3).
  - A chapter describing the physical and biological processes operative at the sediment-water interface (Chapter 4).
- A series of chapters describing sediment risk assessment approaches including:
  - A chapter on how to design risk assessment programs to support risk management decisions (Chapter 5).
  - A chapter on biological effects that usually define the risks that contaminants in sediments represent and the biological assays used to assess those risks (Chapter 6).
  - A chapter on assessing bioavailability via chemical measurements, primarily through the use of porewater concentration measurements (Chapter 7).
- A series of chapters describing sediment risk management, i.e., remedial approaches and their design, including:
  - A chapter on processes describing how to develop and implement risk management efforts (Chapter 8).
  - A chapter on each of the key approaches to managing contaminated sediments: monitored natural recovery (Chapter 9), intrinsic biotransformation and biodegradation (Chapter 10), *in situ* treatment via carbon amendments (Chapter 11), *in situ* containment via capping either with inert material or with active amendments (Chapter 12), and dredging and excavation (Chapter 13).
  - A chapter on the design and implementation of a monitoring program to evaluate remedy performance (Chapter 14).

In addition to the above, the final chapter in the volume (Chapter 15) seeks to identify key uncertainties and resulting research and development needs for the assessment and management of contaminated sediments.

In any single volume covering an area this broad, there are many topics that are not discussed, but it is hoped that the topics that are emphasized represent the state of the practice of contaminated sediment assessment and management and that the most important and commonly needed topics are adequately addressed. It is sincerely hoped that the volume will be useful to the technical practitioner as well as the research scientist and engineer in the field.

SERDP and ESTCP are committed to the development of new and innovative technologies to reduce the cost of remediation of soil, groundwater, and sediment contamination as a result of past operational and industrial practices. We are also firmly committed to the widest dissemination of these technologies to ensure that our investments continue to yield savings for not only the DoD but also the nation. In facilitating this monograph series, we hope to provide the broader remediation community with the most current knowledge and tools available in order to encourage full and effective use of these technologies.

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About the Editor

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Dr. Reible is the Bettie Margaret Smith Chair of Environmental Health Engineering in the Department of Civil, Architectural and Environmental Engineering and the Director of the Center for Research in Water Resources at the University of Texas at Austin. He received his MS and PhD degrees in Chemical Engineering in 1979 and 1982, respectively, from the California Institute of Technology after a BS in Chemical Engineering in 1977 from Lamar University, Beaumont, TX. Prior to joining the University of Texas in 2004, he was the Chevron Endowed Professor of Chemical Engineering at Louisiana State University and the Director of the Hazardous Substance Research Center/South and Southwest.

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Dr. Menzie is a Principal Scientist and Director of Exponent's Ecological and Biological Sciences practice. He received his BS in Biology from Manhattan College and MA and PhD degrees in also in Biology from City College of New York. Dr. Menzie's primary area of expertise is the environmental fate and effects of physical, biological, and chemical stressors on terrestrial and aquatic systems. He has worked at more than 100 hazardous waste sites, including many high-profile Superfund sites and natural resource damage assessment (NRDA)-related cases. Dr. Menzie has considerable experience with the development of risk-based approaches in support of remedial investigations for individual potentially responsible parties (PRPs) as well as PRP groups. He is the coinventor of SediMite™, a low-impact method for remediating contaminated sediments. Dr. Menzie participated in the development of the ASTM Standard for risk-based corrective action (RBCA) and served on the National Research Council's Committee on Bioavailability of Chemicals in Soils and Sediments.

Karen A. Merritt

Dr. Merritt has over 15 years of experience in characterizing fate, transport, and risks of industrial pollutants in aquatic (benthos) ecosystems employing chemical fate and transport analysis, chemical speciation modeling, and application of weight-of-evidence approaches (e.g., sediment quality triad). Dr. Merritt holds a PhD in Environmental Engineering and dual MS degrees in Environmental Engineering and Environmental Chemistry from the University of Maine as well as a BA in Geology from Carleton College. She has consulted for the private and public sectors in the United States and Canada and has taught courses in marine science and marine systems engineering. She has published extensively in the peer-reviewed literature on mercury and methylmercury cycling in sediment, and determination of the effectiveness of capping as a remedy for sites with elevated metal and/or organic chemical concentrations in sediment.