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# Groundwater Contamination by Organic Pollutants

## Analysis and Remediation




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AMERICAN SOCIETY OF CIVIL ENGINEERS

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# Groundwater Contamination by Organic Pollutants

## Analysis and Remediation

Edited by
Jagath J. Kaluarachchi

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Abstract: Groundwater contamination by organic pollutants has become an important topic since the early 1980s due to detection of large-scale contamination events. Since that time, substantial research efforts have been focused on developing new and innovative technologies and management approaches to clean up organic-contaminated sites. With the development of new and effective technologies, current research efforts are now more focused on risk assessment and management at contaminated sites, and remediation in complex geological environments. Although research, technology transfer, and public education have been active links of the overall effort, still there is limited technology transfer and understanding of common remediation technologies and corresponding analysis among practitioners and managers. The goal of this monograph is to provide some insight into the remediation technologies associated with the saturated subsurface and corresponding analysis. It is intended to improve the understanding of both existing practitioners and beginning engineers, geologists, water chemists, and biologists.

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| 80 | Ship Channel Design |
| 81 | Guidelines for Cloud Seeding to Augment Precipitation |
| 82 | Odor Control in Wastewater Treatment Plants |
| 83 | Environmental Site Investigation |
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| 98 | Conveyance of Residuals from Water and Wastewater Treatment |
| 99 | Environmental Site Characterization and Remediation Design Guidance |
| 100 | Groundwater Contamination by Organic Pollutants: Analysis and Remediation |

# TABLE OF CONTENTS

CONTRIBUTING AUTHORS ..... viii

FOREWORD ..... ix

1 MODELS FOR DESCRIBING MULTIPHASE FLOW AND TRANSPORT OF CONTAMINANTS ..... 1
*Zafar Adeel, James W. Mercer, and Charles R. Faust*
1.1 Overview ..... 1
1.2 Physico-Chemical Factors Affecting NAPL Mobility ..... 3
1.3 Modeling of Multiphase Movement ..... 13
1.4 Available Computational Models ..... 14
1.5 Multiphase Models for Remediation Technologies ..... 19
1.6 General Limitations of Multiphase Models ..... 23
1.7 Case Histories ..... 25
1.8 References ..... 32

2 A SCREENING APPROACH TO SIMULATION OF AQUIFER CONTAMINATION BY FUEL HYDROCARBONS (BTEX AND MTBE) ..... 41
*James W. Weaver and Randall J. Charbeneau*
2.1 Introduction ..... 42
2.2 The Hydrocarbon Spill Screening Model ..... 42
2.3 Data Sets ..... 53
2.4 Application of HSSM to a Field Site ..... 58
2.5 Nature of the Hagerman Avenue Plumes ..... 58
2.6 Analysis of Data from Hagerman Avenue ..... 61
2.7 Simulation of Hagerman Avenue ..... 68
2.8 Conclusions ..... 74
2.9 Acknowledgments ..... 75
2.10 References ..... 75

3 **PUMP-AND-TREAT FOR REMEDIATION AND PLUME CONTAINMENT: APPLICATIONS, LIMITATIONS, AND RELEVANT PROCESSES** ..... **79**
*Tissa H. Illangasekare and Danny D. Reible*
3.1 Introduction ..... 80
3.2 Case Studies ..... 82
3.3 NAPL Entrapment and Contaminant Processes during Pump-and-Treat ..... 94
3.4 Experimental Demonstration of Dissolution under Residual and Macroscale Entrapment ..... 111
3.5 Summary and Conclusions ..... 115
3.6 Acknowledgments ..... 117
3.7 References ..... 117

4 **NATURAL BIOATTENUATION OF ANAEROBIC HYDROCARBONS AND CHLORINATED SOLVENTS IN GROUNDWATER** ..... **121**
*Robert C. Borden*
4.1 Introduction ..... 121
4.2 Processes Controlling Contaminant Distribution, Transport, and Attenuation in the Subsurface ..... 122
4.3 Biotransformation of Petroleum Hydrocarbons and Related Compounds ..... 124
4.4 Biotic and Abiotic Transformation of Chlorinated Aliphatic Hydrocarbons ..... 133
4.5 Assessment of Natural Attenuation ..... 140
4.6 Mathematical Models of Natural Attenuation ..... 142
4.7 Future Research ..... 144
4.8 References ..... 145

5 **STEAM FLOODING FOR ENVIRONMENTAL REMEDIATION** ..... **153**
*Ronald W. Falta*
5.1 Introduction ..... 153
5.2 Thermophysical Aspects of Steam Remediation ..... 156
5.3 Numerical Modeling of Steam Injection for Remediation ..... 168
5.4 Field Studies ..... 181
5.5 Summary and Conclusion ..... 189
5.6 References ..... 189

6 **AIR SPARGING TECHNOLOGY: THEORY AND MODELING OF REMEDIAL DESIGN SYSTEMS** ..... **193**
*Cris B. Liban*
6.1 Introduction ..... 194
6.2 Background ..... 194
6.3 Air Flow Modeling ..... 201
6.4 Air Sparging Screening Tools ..... 205
6.5 Bioventing ..... 207
6.6 Vertical Pipe Modeling ..... 207
6.7 Horizontal Pipe Modeling ..... 219

6.8 Pulsed Air Flow ..... 220
6.9 Air Sparging and Biosparging ..... 221
6.10 Summary ..... 223
6.11 References ..... 226

**INDEX** ..... **233**

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# FOREWORD

Groundwater contamination due to organic contaminants is a common occurrence in the United States and elsewhere. The detection of large-scale groundwater contamination in the United States in the early to mid-1970s brought about the implementation of two important federal acts: the Resources Conservation and Recovery Act of 1976 (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, or Superfund). With the initiation of these acts, research related to soil and groundwater remediation accelerated and opened the public debate on health hazards caused by contaminated drinking water. The detailed investigation of early contaminated groundwater sites revealed that hazardous organic contaminants ranging from gasoline to chlorinated solvents were responsible for these widespread environmental problems. It was also found that these contaminants entered the valuable drinking water aquifers due to leaks and spills of underground storage tanks and pipelines as well as unauthorized disposal of hazardous wastes.

When large-scale groundwater contamination was first detected, remediation technologies were almost nonexistent, except pump-and-treat technology. Therefore, great emphasis was placed by federal, state, and private agencies on developing innovative technologies to treat contaminated groundwater so that health risks would be minimized and drinking water sources preserved. However, early progress in remediation technologies was slow because of the lack of understanding of the physical, chemical, and biological processes that control the fate and transport of organic contaminants in the subsurface as well as the complexity of the chemicals themselves. The processes controlling the environmental fate of organic chemicals in the vadose zone are different from those in the saturated zone. Similarly, different organic chemicals—ranging from hydrocarbons to dense solvents—react differently to subsurface conditions. Even in the presence of these difficulties and other limitations, such as subsurface heterogeneity, researchers have developed many innovative technologies to remediate aquifers contaminated with hazardous waste.

This monograph highlights some of the important remediation technologies used in the remediation of contaminated aquifers and their associated analysis. Chapter 1 presents models of multiphase flow systems that are commonly observed in organic-contaminated aquifers. It discusses previous modeling work to predict flow and transport in multiphase systems and currently available modeling software for remediation purposes. Chapter 2 deals with a simple screening model available for the flow and transport of fuel hydrocarbons in aquifers that can be readily used with minimal data. It also discusses a field application to describe the applicability of the model in actual scenarios. Chapter 3 discusses the most popular and oldest remediation technology: pump-and-treat. Although the technology has been known for decades, the limitations of this approach compared with more innovative technologies became known only in recent years. The focus is on these limitations and how they should be considered in implementing the technology. Chapter 4 deals with one of the most promising and cost-effective technologies: bioremediation, which is suitable for organic pollutants, especially fuel hydrocarbons. The emphasis is on the natural attenuation of hydrocarbons and solvents in aquifer systems, with a review of previous work and the potentials of this approach for contaminated aquifers. Chapter 5 covers an important technology known as steam flooding, which can be readily applied to aquifer systems. Because of the complexity and cost of remediation technology, a good understanding of the processes controlling the technology is needed. The focus is on the theoretical formulation of the simulation problem, existing software for remediation design, and the field applications of the technology. Chapter 6 discusses another important technology: air sparging. It provides insight into the air sparging technology in areas of processes controlling the technology and in past field applications.

I acknowledge all the reviewers; members of the Blue Ribbon Panel of the ASCE; members of the Groundwater Quality Committee of the Environmental Engineering Division of the ASCE—especially Ashok Pandit, Bijay Panigrahi, and Lakshmi Reddi; and executive committee members Udai Singh and Bob Williams for providing the necessary support and encouragement. Finally, I thank the contributing authors for their effort and valuable contributions to this monograph.

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# Chapter 1

# MODELS FOR DESCRIBING MULTIPHASE FLOW AND TRANSPORT OF CONTAMINANTS

*Zafar Adeel, James W. Mercer, and Charles R. Faust*

**Abstract**

The presence of nonaqueous-phase liquids (NAPLs) in a wide range of contaminated sites has created the need for a thorough understanding of the relevant characteristics and processes. Over the years, many models have been developed to improve this understanding and help design effective remedial strategies. This chapter is an introduction to the existing and ever-expanding choice of models that deal with multiphase flow problems. Most models currently available are limited in the type of remediation technologies that may be simulated; hence, the discussion is categorized according to the type of technology. An overview familiarizes the reader with the various chemical and physical phenomena that are pertinent to these models. Almost all modeling applications still require some simplifying assumptions, which must be carefully selected and evaluated. It is crucial to clearly understand the effect of making certain assumptions on the modeling outcome. Two case studies of model application to real-world contaminated sites are presented to highlight the importance of adequate selection of models and key simplifying assumptions.

## 1.1 OVERVIEW

Nonaqueous-phase liquids (NAPLs) are often encountered or suspected at contaminated sites, particularly at chemical production and industrial manufacturing facilities (Atwater 1984; Mercer et al. 1985;