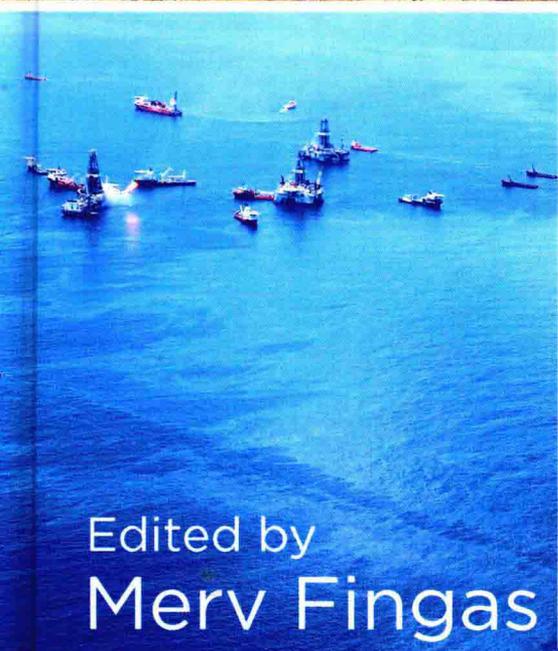


Handbook of

Oil Spill Science and Technology



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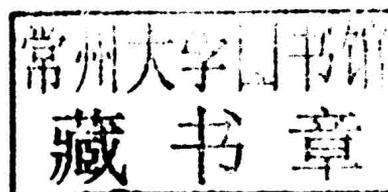
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HANDBOOK OF OIL SPILL SCIENCE AND TECHNOLOGY

Edited by

MERV FINGAS

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HANDBOOK OF OIL SPILL SCIENCE AND TECHNOLOGY

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Dr. Joan Albaigés is Emeritus professor of the Spanish Research Council (CSIC). He established in 1979 at the CSIC (Barcelona), the Department of Environmental Chemistry, where pioneering and internationally well-known research activities on environmental organic chemistry, biogeochemistry of continental and marine waters, and ecotoxicology of organic pollutants started to develop. He spent 10 years as a consultant for the UNEP Regional Seas Program, keeping a personal engagement in promoting marine monitoring programs with developing countries, particularly in Latin America. He was appointed vice-chairman of the Scientific Advisory Committee on the Prestige accident (2002), coordinator of the European Network on Accidental Marine Pollution (Ampera) (2004) and, since 2010, of the ERA-Net "Towards integrated European marine research strategy and programs" (SEAS-ERA), which groups 20 countries. He is also member of the oil spill identification expert group (OSINET) and responsible for the Spanish reference laboratory for oil spill identification. He has contributed over 250 refereed articles to scientific journals, being editor-in-chief of the *International Journal of Environmental Analytical Chemistry*. Prof. Albaigés has been the recipient of several awards, including the Award for Nature Conservation (Osborne Foundation, 1973), the Award for Mass Spectrometry (Hewlett-Packard, 1986), the Monturiol Award for Science Merit (Government of Catalonia, 1989), and the Spanish Research Award on Coastal and Marine Pollution Studies (2007). He has also been elected member of the European Academy of Sciences and Arts, the Academia Europaea, and the Royal Academy of Sciences and Arts (Spain).

Dr. C.J. Beegle-Krause is an oceanographer interested in finding better answers for the Decision Support questions. Most interested in Lagrangian drift problems, such as oil spills, marine debris, and larval fish modeling, she sees that

the greatest need now is to develop new models for oil-in-ice and to leverage new types of analysis, such as Lagrangian coherent structures. Currently, she is a senior researcher at SINTEF in Norway, and previously she was president of Research4D, a small nonprofit in Seattle, WA, and a senior scientist at RPS ASA. Most of her early career was spent in her first position at the NOAA Office of Response and Restoration. She has worked on over 200 spills and was a lead trajectory modeler for the United States during her last 5 years. In 2010, she was recalled to work on the Deepwater Horizon oil spill. Oil spill issues are inherently interdisciplinary, frequently require decisions among trade-offs, and solutions need to be collaborative. She graduated with a B.S. from Caltech in biology, M.S. from University of Alaska Fairbanks in physical oceanography and Ph.D. from the University of Washington in physical oceanography. She also was a member of the U.S. World Cup Team in Fencing.

Dr. Ana Bernabeu is associate professor at the University of Vigo (Spain). She has a Ph.D. on marine science from the University of Cantabria (Spain). Her field of expertise is marine geology and sedimentary dynamics. She has authored about 80 papers (mostly in international journals) and regularly gives presentations and invited talks on these topics in international venues. She has led OILDEBEACH, an important EU effort for the development of an assessment and cleanup protocol of the oil buried in sandy beaches. At present, she is the vice dean for students' mobility and international liaisons at the Marine Science Faculty in the University of Vigo and Associated Editor in the *Journal of Iberian Geology*.

Dr. Carl E. Brown is the manager of the Emergencies Science and Technology Section in the Water Science and Technology Directorate of Environment Canada. Dr. Brown has a doctorate degree in physical chemistry from McMaster

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Dr. Lisa D. Brown is an environmental engineer with work experience in reclamation in the Canadian oil sands and in solid waste management, particularly composting. Dr. Brown completed her Ph.D. in geoenvironmental engineering at the University of Alberta, investigating biological treatment options for organic compounds of concern found in oil sands process-affected waters. Dr. Brown is planning to pursue a career in contaminated sites and/or solid waste.

Harry R. Carter is an independent seabird biologist and consultant who has worked widely on the west coast of North America surveying, monitoring, and studying seabird populations, including rare and endangered species. Since the mid-1980s, he has assisted various aspects of work related to oil spills, including injury assessments, determination of population impacts, assessment of survival of rehabilitated birds, and restoration planning and implementation.

Dr. Sonia Castanedo has a Ph.D. in civil engineering. Since 2011, she is associate professor at the University of Cantabria, in the area of hydraulic engineering, and senior researcher at the Environmental Hydraulics Institute (IH Cantabria). To date, her research has focussed primarily on the study of the morphodynamics of estuaries, numerical modeling and hydrodynamic transport of substances (e.g., oil spills and brine), operational oceanography, and coastal hazards assessment. She has been involved in numerous national and international projects and in more than 20 projects for the Spanish ports and coastal administration. She

has published more than 20 papers in peer-reviewed international journals.

Dr. Daniel P. Costa is a distinguished professor of ecology and evolutionary biology at the University of California at Santa Cruz (CA, USA) where he focuses on the ecology and physiology of marine mammals and seabirds in almost every habitat from the Galapagos to Antarctica. Dr. Costa conducted some of the earliest studies evaluating the effects of crude oil on sea otters in the laboratory and field and he participated in the damage assessment phase of the 1989 *Exxon Valdez* and 2010 *DeepWater Horizon* oil spills.

Dr. Gerhard Dahlmann is senior scientist in section Organic Contaminants of the laboratory of the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH) in Hamburg, Germany. He has been working in the field of oil spill identification since 1978, when he came from the Institute of Fuel Technique, Clausthal-Zellerfeld, which was closely connected at that time to the Institute of Crude Oil Research, Hannover, in order to establish corresponding analytical techniques in the laboratory. At the beginning of the 1980s, pollution by oil was high in German waters. Patches of oil on beaches were frequently observed. After the analytical method was implemented, and especially after GC/MS was available, cooperation with investigating authorities started. Since then, the number of cases, in which spilled oil had to be compared with oil from suspected sources in the framework of criminal proceedings, decreased from more than 120 to about 10–15 per year. Gerhard Dahlmann has written a first publication about the GC/MS method for forensic investigations in cases of oil pollution in 1985, which was followed by publications about the use of the method in single cases. He was the scientific leader of several bigger national and international projects. Findings of these projects were continuously published. He is/was officially participating in international organizations, such as HELCOM, Bonn-Agreement/OTSOPA, and OSPAR-Offshore Industry Committee. In 2005, he became the convenor of the newly established Oil Spill Identification Network of experts within the Bonn-Agreement (Bonn-OSINET), which has got worldwide acceptance, meanwhile.

Dr. Terry D. DeBruyn has over two decades experience in studying and managing bears and his research and management experience includes all three species of North American bears. Between 2008 and 2013, Dr. DeBruyn served as the Polar Bear Project Leader for the U.S. Fish and Wildlife Service in Alaska. He now works for the U.S. Forest Service as the Ecosystems Team Leader in Hiawatha National Forest, Gladstone, Minnesota, USA.

Guido Ferraro, after a degree in Law of the Sea, joined the Italian Coast Guard as aircraft pilot for 15 years. In 1999, he joined the European Commission: first as Seconded National

Expert from the Italian Government and then as permanent staff. He received his Ph.D. on maritime affairs from the University of Ljubljana. All his professional experience is related to maritime issues and he has around 50 scientific publications on this subject.

Ben Fieldhouse is a scientist with 22 years experience in the field of environmental emergencies related to spills of hazardous materials at the Emergencies Science and Technology Section of Environment Canada. He has a B.Sc. in chemistry from York University in Toronto. His primary expertise is the behavior of petroleum crude oils and fuels released into aquatic environments, focussing on the study of water-in-oil emulsions, the impact of oil properties and chemical composition on the behavior of spills on water, and the effectiveness of treating agents as a spill countermeasure. His experience includes a number of field projects and emergency response operations, including large wave-tank trials, in situ burns, remote sensing ground-truthing operations, and contaminated site assessments.

Dr. Dennis M. Filler practices forensic engineering in Alaska and teaches engineering science at the University of Central Florida. He has published in geoenvironmental and cold regions engineering journals, and has a few book chapters on human impacts and bioremediation in cold regions. Current interests include engineering challenges of the far north and professional engineering education.

Dr. Merv Fingas is a scientist focusing on oil and chemical spills. He was a spill researcher in Environment Canada for over 30 years and is currently working privately in Western Canada. Mr. Fingas has a Ph.D. in environmental physics from McGill University and three masters degrees—chemistry, business, and mathematics—all from University of Ottawa. His specialities include spill dynamics and behavior, spill treating agent studies, remote sensing and detection, and in situ burning. He has over 800 papers and publications in the field. In his 40 years' career, he has published eight books on oil and hazardous materials. Dr. Fingas had been editor of the *Journal of Hazardous Materials* for 6 years. He has served on two committees on the U.S. National Academy of Sciences on oil spills including the recent "Oil in the Sea." He is chairman of several ASTM and intergovernmental committees on spill matters.

Dr. R. Glenn Ford is a modeler and biologist whose focus is on the spatial distribution of marine vertebrates, seabird foraging behavior, and the impacts of oil spills on seabirds. Since 1986, he has led modeling efforts to estimate seabird mortality resulting from most major oil spills in U.S. waters, including the 1989 *Exxon Valdez* (AK, USA) and 2010 MC-252 *DeepWater Horizon* oil spills (Gulf of Mexico, USA).

Dr. D. Michael Fry is an avian ecologist and toxicologist whose work has focused on the effects of pesticides, plastics,

polychlorinated biphenyls, and oil spills on wild birds. He is the author of over 50 scientific publications and coauthor of 10 books and book chapters. Dr. Fry was on the faculty of the Department of Avian Sciences at University of California, Davis, for two decades, at the American Bird Conservancy in Washington, DC, and is currently the environmental contaminants specialist for the U.S. Fish and Wildlife Service in Honolulu (HI, USA).

Karen E. Gerhardt is a research associate at the University of Waterloo, and manager of Research and Administrative Services for Waterloo Environmental Biotechnology Inc., a company that has developed and implemented microbe-enhanced phytoremediation systems. Her background includes research projects in plant biology, microbiology, photobiology, and biochemistry. Dr. Gerhardt has been involved in the fields of plant biology and environmental science for over 20 years and has coauthored more than 80 phytoremediation reports and published papers.

Perry D. Gerwing is a specialist in reclamation and contaminated site assessment and remediation. He has worked as an environmental specialist for large oil and gas corporations and environmental consulting firms for over 25 years. He has coauthored and published many scientific papers, and as president of Earthmaster Environmental Strategies Inc., an environmental consulting firm, has spent a number of years developing and implementing successful phytoremediation programs for clients.

Dr. Bruce M. Greenberg is trained as a chemist and biochemist. He is a professor at the University of Waterloo and president of a spin-off company, Waterloo Environmental Biotechnology Inc., which specializes in innovative phytoremediation solutions. He has over 30 years of experience in environmental biology and chemistry, and has published more than 160 papers.

Dr. Roger C. Helm is the Chief, Division of Environmental Quality, and a senior science advisor for the U.S. Fish and Wildlife Service (Service). He co-lead field investigations determining the impact of the 1989 Exxon Valdez oil spill (AK, USA) on nearshore communities and served as science advisor on the natural resource damage assessment (NRDA) on the 2010 MC-252 DeepWater Horizon oil spill (Gulf of Mexico, USA). Dr. Helm has worked as the lead scientist and in his service has pursued more than 30 NRDA and restoration cases involving oil spills and chemical contamination in the United States and internationally. He has coauthored dozens of technical and peer-reviewed publications on the impact of oil on birds and wildlife and coauthored a book *Marine Mammals of California*.

Dr. Bruce P. Hollebone Bruce Hollebone is a chemist with 17 years of experience in the field of chemical and oil spill research and development. He has a Ph.D. in chemistry from

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Dr. Xiao-Dong Huang received his bachelor degree in agronomy in 1982 from Agricultural University of Heilongjiang, China, and his M.Sc. and Ph.D. in Biology in 1991 and 1995, respectively, from University of Waterloo of Canada. He was an agronomist from 1982 to 1990 at the Agricultural and Land Reclamation Academy of Heilongjiang Province, China. He spent 2 years at Wright State University of Ohio for postdoctoral research (1996–1998). He was an adjunct professor at the University of Waterloo from 2004 to 2010. From 2009 to present, he has been vice president of Waterloo Environmental Biotechnology Inc. Dr. Huang's research experience in China was in crop protection and hydroponics. He and his group at state farms of Northern China researched and developed systems to reduce the chemical usage in crop protection. His research activities focused on environmental toxicology and phytoremediation since 1989. He has been actively involved in research and development of methods for assessment of contaminants by using plants and engaged in development of phytoremediation systems for removal of persistent organic and inorganic contaminants from soils. Dr. Huang has completed and managed many scientific research and development projects and has extensive field experience on agronomy, environmental chemistry, environmental toxicology, and phytoremediation. He has over 50 referred scientific publications.

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Paul G.M. Kienhuis works at the lab of the Ministry of Environment and Infrastructure and has 35 years'

experience in analytical chemistry. Since 1999, he has been responsible for the identification of waterborne petroleum and petroleum products from the inland waters of the Netherlands and the Dutch part of the North Sea. He has to handle about 25 cases a year ranging from small diesel overruns to large spills of HFO in harbors. Oil spill identification is used to confirm responsibility in illegal discharges, but also to reclaim cleaning costs for contaminated quays and ships in harbors. In 2004, together with Dr. G. Dahlmann (BSH, Hamburg) he started with an annual international ring test for oil spill identification to share and improve knowledge about analytical techniques and limitations in comparing oil samples. In 2005, on request of Bonn Agreement (an agreement by North Sea coastal states to protect the environment), Gerhard Dahlmann and Paul Kienhuis started an oil spill identification expert group (OSINET). OSINET has worked on a now generally accepted method for oil spill identification (CEN/Tr 15522) that has been published by CEN in 2006 and an updated version in 2012.

Dr. Mahlon C. Kennicutt II received a Bachelor of Science degree in chemistry from Union College, Schenectady, NY (1974), and a Ph.D. in oceanography from Texas A&M University, College Station, TX (1980). He was a founding member, worked for 23 years as research scientist, and rose to director of the Geochemical and Environmental Research Group from 1998 to 2004. Dr. Kennicutt was the director of Sustainable Development (2004–2009) and led the Sustainable Coastal Margins Program (SCMP) from 2000 to 2010. He returned to the Oceanography Department and the Environmental Programs in 2009 where he taught oceanography, polar science, and science and policy retiring in 2013. He was a member of the U.S. Department of State delegation to the Antarctic Treaty from 2002 to 2007. Dr. Kennicutt was the U.S. delegate to the Scientific Committee on Antarctic Research (SCAR) from 2003 to 2012 and ex officio member of the U.S. Polar Research Board from 1998 to 2014. He served as a vice president (2004–2008) and president of SCAR (2008–2012). He was the principal investigator of the long-term environmental monitoring program in McMurdo Sound in Antarctica from 2002 to 2014 and has been to Antarctica eight times. He is professor emeritus of oceanography at Texas A&M University and led the first SCAR Antarctic and Southern Ocean Science Horizon Scan in 2014. Professor Kennicutt was named a National Associate of the U.S. National Academy of Sciences for life, awarded the Antarctic Service Medal of the U.S. Antarctic Program, and a geographic feature was officially named Kennicutt Point in 2006.

Dr. Andrew G. Klein is an associate professor in the Department of Geography at Texas A&M University. He received a B.A. from Macalester College and a Ph.D. in geological sciences from Cornell University. His current research interests lie in the application of remote sensing and geographic information science (GISci) techniques to study

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Mike Landriault is a senior research technician in the Emergency Science and Technology Section (ESTS), Environment Canada, Ottawa, Canada. He has worked for over 20 years in oil spill forensic identification and emergency chemical spill analysis. He is a veteran of instrumental analysis using techniques such as gas chromatography and high-performance liquid chromatography–mass spectroscopy. Mr. Landriault received his diploma in chemical engineering technology from Algonquin Collage, Ottawa, Canada. He has coauthored over 70 academic publications including over 30 peer-reviewed journal articles.

Dr. William J. Lehr is senior scientist at the Office of Response and Restoration of the National Oceanic and Atmospheric Administration (NOAA). He was previously Spill Response Group Leader for the same organization. Dr. Lehr has also served as an adjunct professor for the World Maritime University and oil spill consultant for UNESCO. Dr. Lehr is a world-recognized expert in the field of hazardous chemical spill modeling and remote sensing of oil spills. He has served as guest editor for the journal *Spill Science and Technology* and the *Journal of Hazardous Materials*, and as cochair of the International Oil Weathering Committee. NOAA and the United States Coast Guard have awarded him several medals for his spill response efforts at major spill incidents of national or international significance. He has numerous publications in the field. Dr. Lehr holds a Ph.D. in physics from Washington State University.

Dr. Qianxin Lin is an associate professor of Department of Oceanography and Coastal Sciences, School of the Coast and Environment, Louisiana State University. Dr. Lin has conducted a variety of wetland oil spill–related research projects and accumulated an extensive oil spill–related experience in the past 20+ years. His oil spill related–areas of expertise primarily include factors controlling impact, recovery and fate of oil spills in wetlands, bioremediation, phytoremediation, *in situ* burning and restoration of oil spill–impacted coastal wetlands, and effects of oil spill dispersants on coastal marsh vegetation.

Dr. Carmen Morales-Caselles is a research scientist at the Ocean Pollution Research Program in the Vancouver Aquarium. Currently she is focused on establishing a coastal monitoring program in the Coast of British Columbia to assess the presence of contaminants in sediments and their effects on the marine biota. Other areas of interest include ecotoxicology of persistent pollutants, microplastics, food web modeling, and the development of quality guidelines.

As part of her Ph.D., Morales developed integrated studies to assess oil-contaminated sediments from the Prestige oil spill. She also spent more than 4 years working as a consultant at IOC-UNESCO where she was closely involved in the coordination of an ICAM project on biological marine indicators in Latin America plus other UN initiatives.

Dr. Rocío L. Moreno is a postdoctoral research fellow at the British Antarctic Survey (Cambridge, UK). Together with Dr. Sanpera, she studied the long-term effects of the *Prestige* oil spill on seabirds.

Oliver Muellenhoff joined Shell in January 2012 as remote sensing consultant in the Survey Operations team. Previously he worked for the European Commission Joint Research Centre as scientific/technical support officer in the field of applied remote sensing and for BMT ARGOS as remote sensing specialist which focused on the AgipKCO North Caspian Sea project. Oliver studied geology and obtained a Ph.D. in geosciences from Westphalian Wilhelm's University Muenster in 2004.

Dr. Alia Bano Munshi is a scientist involved in the research of POPS for last 30 years in PCSIR. She is doctorate in marine chemistry from Xiamen University, China. Dr. Alia received a postdoctorate from the Baltic Sea Research Institute, Germany, on a scholarship by DAAD and from Virginia Tech. State University, Blacksburg, Virginia, USA, on a Fullbright scholarship and from the University of HULL, UK. She has more than 50 research publications and papers. Her specialities include polychlorinated biphenyls, polycyclic aromatic hydrocarbons, pesticides, phthalates, alkyl phenols, and steroids in the marine environment. Dr. Alia has four books published in her career. Presently establishing the dioxin testing facility in fish meat with the collaboration of UNIDO.

Dr. Thomas J. O'Shea an emeritus scientist at U.S. Geological Survey, has studied the ecology of sirenians and other mammals and has expertise on the occurrence and effects of environmental contaminants in wildlife. He has authored or coauthored nearly 150 scientific papers, monographs, and books and is currently an associate editor of the journal *Marine Mammal Science*.

Dr. Araceli Puente is biologist and has a Ph.D. in marine sciences from the University of Cantabria. She is currently associate professor at the University of Cantabria and senior researcher at the Environmental Hydraulics Institute. Much of her teaching is linked to the Master of Science in Environmental Management of Water Systems. Her research focuses on the environmental assessment and monitoring of aquatic systems and the description of the spatial–temporal patterns of estuarine and coastal ecosystems, with particular focus on the study of the ecology of benthic communities (invertebrates and macroalgae).

Dr. Carolina Sanpera is a professor at the Department of Animal Biology, University of Barcelona (Spain). Her research focus is on trophic ecology and ecotoxicology of aquatic birds. Together with Rocío Moreno, Dr. Sanpera studied the long-term effects from the *Prestige* oil spill on seabirds.

Dr. Dagmar Schmidt Etkin has 39 years of experience in environmental analysis—14 years investigating issues in population biology and ecological systems, and 25 years specializing in the analysis of oil spills. Since 1999, she has been president of Environmental Research Consulting (ERC), specializing in data analysis, environmental risk assessment, spill response analysis, cost analyses, expert witness research and testimony, and development of comprehensive databases on oil/chemical spills and spill costs. ERC's work focuses on providing regulatory agencies and industry with sound scientific data and perspectives for responsible environmental decision-making. Dr. Etkin received her B.A. in biology from the University of Rochester, and her M.A. and Ph.D. in organismic and evolutionary biology from Harvard University where she specialized in ecological and population biology modeling and statistical analyses. She is a member of the UN Joint Group of Experts on the Scientific Aspects of Marine Protection (GESAMP), the International Maritime Organization (IMO) Marine Environmental Protection Committee Correspondence Group on Environmental Risk Assessment Criteria, and the UNH/NOAA Coastal Response Research Center Working Group on Oil Spill Modeling.

Dr. Hina Ahsan Siddiqi is a scientist of PCSIR (Pakistan Council of Scientific & Industrial Research), is doing research in the field of persistent organic pollutants for past 10 years. Her specialities include pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons, and relevant monitoring, assessment, and method development. Ms. Hina acquired Ph.D. in analytical chemistry from University of Karachi, Pakistan. Ms. Hina was awarded internship at International Atomic Energy Agency (IAEA) and completed her Ph.D. research at Agrochemical Unit of FAO/IAEA Training & Reference Center for Food and Pesticide Control, Agriculture and Biotechnology Laboratory, Seibersdorf, Austria. Dr. Hina has 20 research publications and papers. She has written many chapters for different books, which are in progress for publishing. Presently, Dr. Hina is engaged in establishing the dioxin testing facility in fish at PCSIR with the collaboration of UNIDO and it would be a first-response organization in the region.

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PREFACE

Oil spill studies continue to evolve. While there are few books on the topic, there are regular conferences and symposia. This is the first scholarly book on the topic of oil spills. As such, this book focuses on providing material that is more scholarly and somewhat involved. While every attempt was made to include the essential material, there may be some gaps. The importance of many subtopics changes with time and current spill situations.

All materials in this book, including introductions, have been peer reviewed by at least two persons. The following peer reviewers are acknowledged (in alphabetical order): Dan Anders, Perihan Aysal, Ken Biggar, Robert Bonke, James Botkin, Jennifer Boyce, Joan Bradock, Tom Brody, Carl Brown, Ian Buist, Ron Delaune, Merv Fingas, Anita George-Ares, Lisa Gieg, Ron Goodman, Kurt Hansen, Sarah Harrison, Jocelyn Hellou, Bruce Hollebhone, Alan Judd, Tom King, Davor Kvočka, Pat Lambert, Robin Law, Bill Lehr, Ira

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A special thanks goes out to the authors, many of whom put in their own time to complete their chapters. This is especially true because many of the authors were working on the Deepwater Horizon spill during the preparation of this book. This “double-duty” was greatly appreciated. The author’s names appear throughout the text. Following this forward, I have a brief biography of each of them.

I also like to thank the many people who provided support and encouragement throughout this project. I also thank Environment Canada and my former colleagues for help and support. Environment Canada is acknowledged for permission to use materials and photos.

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