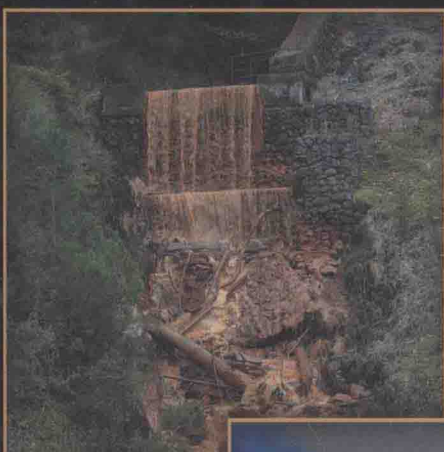
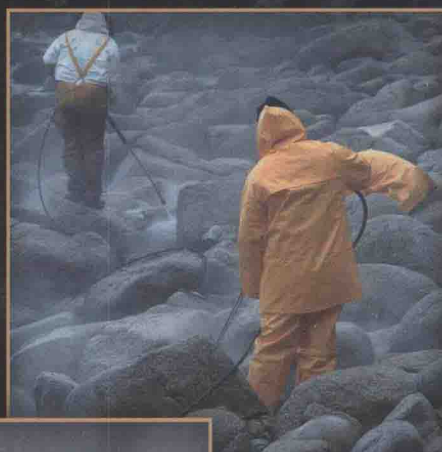
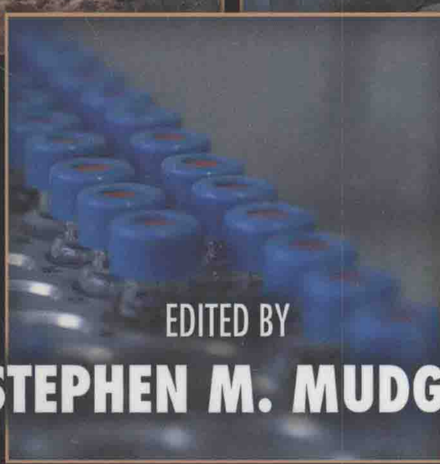
METHODS IN ENVIRONMENTAL FORENSICS







EDITED BY

STEPHEN M. MUDGE

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METHODS IN ENVIRONMENTAL FORENSICS

Preface

'The best laid schemes o' mice an' men' (Robert Burns, 1786, 'To a Mouse')

This book has been in preparation for much longer than was originally intended. However, I am pleased to say that the chapters presented within are written by experts in their various fields of environmental forensics. This book represents our state of knowledge in these areas and provides a reference for all wishing to practice environmental forensics and, indeed, any environmental investigation.

Environmental forensics (EF) has been around for decades but we have not always called it that. As a scientific community we have been investigating the source and fate of contaminants in the environment and, occasionally, these findings have been used to reduce or mitigate pollution and prosecute offenders. The word *forensics* is derived from the Latin *forum*—a meeting place where judicial issues were presented to the people. Initially, we were concerned about 'crimes against the person', but as we have become more aware of the damage done to our environment by indiscriminate waste disposal, we have strengthened legislation that protects the air we breathe, the water we drink, and the ground we live on. We have also become aware of the toxic nature of the chemicals we had previously taken for granted or thought were benign. It has been suggested that the Roman Empire fell because of the lead in its wine and water; modern food standards agencies would have a field day with that one!

In the past decade, however, there has been a crystallisation of the vague term 'environmental forensics' into a well-disciplined science that integrates sampling design, analytical chemistry, and environmental processes with the legislative framework. As with any science, though, it needs to be rigorously applied and the correct methods used for the study at hand; there is no one ideal method that would solve all problems. There are two journals specifically covering this discipline (*Environmental Forensics*, founded by Bob Morrison and now published by Taylor & Francis, and *Journal of Environmental Monitoring*, published by the Royal Society of Chemistry). If these two august publishing houses are publishing our science, it must have been accepted into the mainstream of scientific advancement.

In some cases of environmental contamination, the EF practitioner is called in rather late and often presented with a very limited budget with which to prove everything. Rigorous science that would stand up in court must also stand up to scientific peer review with replication, errors, significance, and certainty—always difficult to do with a small budget. However, a lot can be achieved without the latest, most expensive piece of scientific equipment; it comes down to the ingenuity of the investigator.

This book outlines the methods that have worked well in past EF cases. The first chapter describes how an environmental case might be approached from inception to court testimony. It is worth noting that in proving that X was responsible, it is almost as important to prove that it could not have been Y or Z. In chapter 2, David Assinder outlines the ways in which natural and artificial radionuclides can be used as tracers of environmental processes and for dating samples from the field, an important aspect when apportioning blame. Zhendi Wang (with Carl Brown) from Environment Canada has provided an excellent review of the methods used for oil spill identification—still a major cause for environmental concern around the world. The ubiquitous nature of oil and its products can make source identification very complex, especially in harbours.

This chemical composition approach is followed by Paul Philp and Tomasz Kuder's chapter on the use of stable isotopes (especially ^{13}C and ^{2}H) to improve source specificity, including with oil spills. This approach has wide application outside oil identification and can be used to track multisource compounds through complex environmental processes. Claudio Bravo-Linares and I have recently developed a significantly more sensitive method for the analysis of volatile organic compounds (VOCs) exploiting the new solid phase microextraction (SPME) technologies. This has been used in tracking the source of VOCs in the atmosphere, waters, sediments, and soils. Chlorinated solvents remain an important contaminant in groundwaters and form the basis of many EF cases in the United States.

In a slight shift away from the chemistry of the environment to the biota that live in it, Andrew Ball (with Jules Pretty, Rakhi Mahmud, and Eric Adetutu) presents a range of methods for the molecular characterisation of soil bacteria that can greatly assist in their identification, treatment regimes, and geographic origin. Angel Borja and Iñigo Muxika show how the macrobiological community or assemblage may be used to classify an area and quantify the degree of stress exerted on the system. These methods are being applied in the implementation of the EU Water Framework Directive. Gavin Birch (with Andy Russell and me) presents a range of methods for the normalisation of data to remove a range of natural effects that may mask environmental processes. Concentration gradients of contaminants can exist purely due to changes in the grain surface area (mud to sand), although these may not represent anthropogenically induced gradients. Similarly, I present a range of statistical methods for the treatment of chemical and biological data to determine the underlying trends within a complex multivariate environment. Geostatistics is often used to present contour maps and to infer a gradient between source and sink, but how frequently are the prerequisite tests conducted to ensure their validity?

Sometimes, measurements on their own are insufficient. Ian Colbeck outlines a range of modelling techniques to identify sources of atmospherically dispersed contaminants. These have had recent usage when determining the source of foot-and-mouth disease outbreaks in the United Kingdom. Finally, Allan Kanner puts the legal perspective to all of these scientific methods: If one's method is unlikely to be accepted by a court, maybe it is not worth pursuing in this particular case. It is noteworthy that the reference structure in this last chapter is different from the others as it principally cites legal cases regarding the admissibility of data and expert testimony.

I thank all of these experts for their input to this book and hope that it will be used many times in the coming years by students and practitioners of environmental forensics. I must also thank the patience of the publishers, Taylor & Francis—especially Jill Jurgensen and Becky Masterman—for their confidence in the book.

Stephen M. Mudge

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I would like to thank all the contributors to this book; it has taken longer than anticipated but the result is good. I would particularly like to thank Andy Ball from Flinders University, who started the editorial process with me but, due to work pressure, had to drop out. I would also like to thank Bob Morrison, director of the International Society of Environmental Forensics (ISEF), for his encouragement across the years. Finally, I would like to thank Georgina, my wife, and our two children, Xander and Toren, for their understanding when I had to sit at the computer editing the text for the publisher.

The Editor

Stephen Mudge has been conducting environmental forensics investigations for many years; these have principally focused on the identification of the contamination sources, especially in complex, multisource environments. Dr Mudge designed and ran the first undergraduate environmental forensics degree at Bangor University, and students from this course are now active in the commercial sphere. Dr Mudge has acted as an expert witness in several environmental contamination cases and continues to research new methods for the quantification and source apportionment of chemicals around the world.

Contributors

Eric Adetutu
School of Biological Sciences
Flinders University
Adelaide, Australia

David Assinder
School of Ocean Sciences
Bangor University
Menai Bridge, Anglesey, United Kingdom

Andrew S. Ball
School of Biological Sciences
Flinders University
Adelaide, Australia

Gavin F. Birch
Environmental Geology Group
School of Geosciences
The University of Sydney
Sydney, Australia

Angel Borja
Marine Research Division
AZTI-Tecnalia Foundation
Pasaia, Spain

Claudio Bravo-Linares
Universidad Austral de Chile
Instituto de Química
Valdivia, Chile

Carl Brown
Emergencies Science and Technology Division, Environmental Technology Centre
Environment Canada
Ottawa, Ontario, Canada

Ian Colbeck
Centre for Environment and Society
Department of Biological Sciences
University of Essex
Colchester, United Kingdom

Allan Kanner
Kanner & Whiteley, LLC
New Orleans, Louisiana

Tomasz Kuder
School of Geology and Geophysics
University of Oklahoma
Norman, Oklahoma

Rakhi Mahmud
Department of Biological Sciences
University of Essex
Colchester, United Kingdom

Stephen M. Mudge
School of Ocean Sciences
Bangor University
Menai Bridge, Anglesey, United Kingdom

Iñigo Muxika
Marine Research Division
AZTI-Tecnalia Foundation
Pasaia, Spain

R. Paul Philp
School of Geology and Geophysics
University of Oklahoma
Norman, Oklahoma

Jules N. Pretty
Department of Biological Sciences
University of Essex
Essex, United Kingdom

Andrew T. Russell
School of Ocean Sciences
Bangor University
Menai Bridge, Anglesey, United Kingdom

Zhendi Wang
Emergencies Science and Technology Division, Environmental Technology Centre
Environment Canada
Ottawa, Ontario, Canada

Contents

1 Approaching Environmental Forensics

STEPHEN M. MUDGE

Contents

Introduction

Environmental forensics may sound like a glamorous, exciting discipline; it certainly can be, but it can have a lot of routine analyses and report writing as well. The subject must be approached in a scientific manner where hypotheses are rigorously tested. One's duty (in the United Kingdom) is to the court, to help resolve the truth of the situation, rather than to any one party, even if that party might be paying for the work to be done (Civil Procedure Rules, Part 35). The definition of *truth* may also be open to question; as scientists, we generally accept hypotheses to be true until such time as we find either a better hypothesis to describe the observations or we find an exception that disproves it. These truths may be real or just our 'best guess' at the present time. This definition of truth may also be different from what a court defines as true since the former may be based on *belief.*

Environmental forensics is a true multidisciplinary subject where chemical, physical, and biological methods combine within a legal framework to determine the origin and extent of environmental contamination. A logical approach is key to success because the work may need to be defended in a court of law and not just to the scientific community. It should be accepted by practitioners that although they are not experts in all aspects of the environment, they may understand the system's functioning well enough to know what analyses would be most appropriate in each case. It may be that simple chemical analyses would be sufficient, but sampling design and quality assurance must go hand in hand to ensure that results are valid. In other situations, more complex statistical methods, dating techniques, or use of biological community data may be needed; the key factor is to know what to do to answer the question and whom to call.

Society's standards change with time—not only concerning behaviour or morals, but also about what we accept with regard to environmental contamination. This is partly driven by improved understanding of the risks associated with chemicals and also because we demand a cleaner environment in which to live. In response to these societal changes, our laws change to meet our expectations. Higher levels of contamination may have been an acceptable price to pay for rapid industrialization 200 years ago, and several of these chemicals may still be around today in the form of contaminated land, groundwater, or marine systems. In environmental forensics, it is necessary to determine the source of any contamination, place that in context both geographically and legally, demonstrate a pathway to a sink, and then show how much is present above the background. This book provides a series of methods and approaches that can be used to do just that; chapters have been written by experts in each field and logically ordered to provide a guide for all practitioners.

Preparation

All good scientific studies and legal cases are well planned; 'perfect preparation prevents piss poor performance' and everything that is a necessary part of good environmental forensics. When invited to take up a case, practitioners should plan their approach carefully before leaving their offices. There are two types of cases, however: Sites that have been contaminated over time and are now being investigated may be approached in a slightly more leisurely manner than ongoing acute (spill) events where speed is of the essence. A different approach to each type of case is required.

Sites

Before approaching a new site, it would be prudent to find out as much as possible about it, if only to direct where samples would be most usefully collected. In this regard, written histories and company records can help a lot. One of the first resources that should be used is maps; this includes standard topographical maps (e.g., U.K. Ordnance Survey) as well as geological maps indicating relief, drainage pattern, and rock and soil type. Not all of these may be available, but efforts should be directed to finding them.

Aerial photographs (Davis et al. 2005) can also have a significant role to play by identifying the assets that were present at the time that the photo was taken. If a series of photographs taken through time is available, key dates can be narrowed down to small ranges (e.g., Davis et al. 2005). This may be of great importance when trying to date particular contamination events or start points for releases. Even Google Earth has been of great help in resolving likely sources of contaminants (Kalin, personal communication).

Physical attributes for sites and past monitoring records can provide an indication of the direction and location of potential sources, contamination plumes, or off-site receptors. Care must be taken when reviewing these data to ensure that no bias is introduced by using the conclusions from previous studies. These studies should be read, but one should draw one's own conclusions from the data.

Events and Spills

In the case of an ongoing event, a plan should be in place to ensure that statistically meaningful results may be gathered from any samples taken. The message here might be 'be prepared'. This means that appropriate sample collection vessels (e.g., glass for organic contaminants and plastic for metals) have already been cleaned and are ready to go. One should also know something about the chemistry of the contaminant (especially the water solubility) so that the correct phase may be collected.

Some pollutants may be transported via the atmosphere, and access to a Gaussian plume dispersion model may provide a rapid assessment of the likely area of maximum impact under the prevailing weather conditions. Details required for accurate prediction of deposition areas include thermal lift of the contaminant, wind direction and strength, depth of the mixing layer, and effects of buildings. Such simple modelling may not be good enough for other needs, but it should at least point the sampler in the correct direction and at the right distance from the source to ensure meaningful sample collection.

With spills, it may be prudent to collect more samples than may be needed as it may not be possible to collect them later. Provided they are correctly stored, many materials should be stable long enough for assessment of the analytical needs, although suitable control samples to determine losses should also be included. In some cases, such as oils spills in harbours, there may be several potential sources of hydrocarbons and the responsible party may not be immediately obvious (Hegazi et al. 2004; Staniloac, Petrescu, and Patroeseu 2001). Therefore, as many potential sources as are in the area should be collected and this may require the assistance of the enforcement agencies to facilitate access.

Legal Framework

For a case to exist in criminal law, some statute must have been contravened and a contamination event must be responsible. Although this may sound easy to assess, many compounds do not have mandatory limits set down in legal texts. Therefore, many of the regulations use catchall statements such as "noxious substance" (e.g., Merchant Shipping and Maritime Security Act 1997) to encompass as many materials as possible. Our laws change with time, especially the secondary instruments underneath the primary legislation (e.g., Statutory Instrument 1998 No. 1153: The Merchant Shipping [Dangerous or Noxious Liquid Substances in Bulk] [Amendment] Regulations 1998), and these should reflect society's acceptance of chemicals in the environment as well as our awareness of the long-term effects of human exposure.

Much of Europe's environmental protection legislation has been derived from EU directives in the last decade. Important pieces of legislation include the Water Framework Directive (2000/60/EC) and the new Environmental Liability Directive (2004/35/CE). EU directives set out the goals, but each member state may implement its own laws to achieve those goals, so there will be differences across the continent.

All this is driving toward a cleaner environment; however, past contamination does not go away just because we have changed the reference values we allow in discharges.

Background versus Baseline

All elements except some of the radioactive ones existed in the environment long before man was active on the Earth. The concentration of these elements varied widely according to the rock type and physicochemical