T R E N D S • I N

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Environmental Forensics: Determining Who, What, When, and Where?

Established and emerging scientific tools are finding application in environmental law.

Forensics is defined as the application of science to law. It follows that environmental forensics is, broadly, the application of science to environmental law. Typically, environmental professionals follow a fairly prescriptive framework, designed to investigate the nature and extent of environmental releases within an established regulatory program. Often, however, the facts most helpful in a legal setting are derived not from samples or analyses required for regulatory compliance, but rather from samples and analyses selected to address specific questions that are, themselves, secondary to the regulatory program.

It is important to bear in mind that these tools can be used to vindicate parties, as well as to implicate them.

From a litigation perspective, the primary issues usually concern determining the age and sources of the contamination. Related questions often include: who is responsible; what is the contribution from each responsible party; what is an equitable cost allocation; and are there any natural resource damages? Environmental forensic problems are almost always best solved by integrating numerous lines of inquiry or analyses to arrive at a coherent understanding. The understanding is then expressed as an opinion that is scientifically defensible and explainable to other litigants, and to non-experts, such as judges and juries.

In criminal forensics, blood typing is used to implicate or exonerate a suspect, and more recently, DNA analysis is being used to verify or refute the identity of a culprit. Similarly, in environmental forensics, the tools outlined in the table help to

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Letter to our Readers

October 1999

Dear Colleague,

Just as detectives work with pathologists to develop forensic evidence of a crime, today environmental lawyers work with fate and transport specialists and environmental chemists to develop chemical evidence to establish culpability or vindicate parties in environmental liability disputes, and to help allocate the cost of remediation in joint and several liability claims.

In this issue of *Trends in Risk & Remediation*, we review the application of established and emerging scientific techniques to environmental liability law, which has come to be called "environmental forensics." We examine how fate and transport tools can be used with field data to identify the source(s) of contamination, or to determine when a release occurred. We also discuss the growing application of advanced analytical techniques to non-hydrocarbon compounds such as dioxins/furans and PCBs.

Contributors to this issue include Dr. Eric Butler, who specializes in the application of advanced petroleum hydrocarbon analytical methods for source identification and site characterization. He is joined by Mr. Manu Sharma, a hydrogeologist who specializes in modeling the transport and fate of environmental contaminants; and Dr. A. Dallas Wait, a Gradient Principal and expert in the use of environmental chemistry to identify the source and fate of chemicals in the environment. We thank Mr. Gregory Bibler, a Partner with Goodwin, Procter & Hoar LLP in Boston, for providing a lawyer's perspective on the use of environmental forensics in environmental liability disputes.

We hope this *Trends* issue provides insights on the tool kit of environmental forensics.

Yours truly,

Neil Shifrin
President

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Environmental Forensics: Determining Who, What, When, and Where?

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narrow the possibilities, or in some cases, establish with scientific certainty, the sources of contamination or the timing of releases. The tools consist largely of chemistry analyses and fate and transport models (see related articles), as well as specialized historical research. It is important to bear in mind that these tools can be used to vindicate parties, as well as to implicate them.

Because of the long-term use of petroleum in our economy, the frequency of releases, and the toxic nature of some of its constituents, petroleum is a frequent subject of environmental forensics. Rudimentary petroleum hydrocarbon fingerprinting analysis consists of a gas chromatographic separation followed by detection of sample components by flame ionization detection (GC/FID) (see *Trends*, Fall 1997). This analysis yields a chromatogram that visually depicts the spilled product and reveals the type of petroleum product (*e.g.*, gasoline, diesel, motor oil, *etc*.). Many times, this simple analysis is sufficient to identify the source of the release and answer a liability question. For example, if the spill is identified as a product that a particular party never handled, then they have been exonerated.

Often however, the situation is more complex. For example, in the case of gasoline releases, one may have to turn to analyses of gasoline additives to provide additional information. Various gasoline additives, such as alkyl lead compounds and oxygenates, were used during distinct time frames in the United States. Their periods of use are well documented. Thus, by establishing the presence of a particular additive component, information can be gained on the history and timing of releases.

Sometimes, a combination of techniques is required to develop a complete understanding of the situation. For example, an initial analysis may establish that the release was leaded gasoline. It may be possible to then determine the age of the release, and thus, the source of the product by analyzing for the lead isotopes. Analysis of carbon isotopes (isotopes of an element have the same number of protons but a different number of neutrons in their nuclei) can sometimes distinguish between gasoline sources because various sources of crude oils, and the products made from them, often differ in their carbon isotope proportions. As such, carbon isotope analyses can be useful in establishing the sources of various petroleum products.

Finally, in recent years, a new set of sophisticated petroleum hydrocarbon fingerprinting analyses have been developed. They pertain mostly to products that are heavier than gasoline. While the simple GC/FID analysis often cannot distinguish between two products of the same type (*e.g.*, two diesel fuels), the new method using GC with mass spectrometry (GC/MS), which looks for many more analytes than prior methods, has proven useful in forensic applications. These GC/MS techniques look for alkylated polycyclic aromatic hydrocarbons (PAHs), including sulfur-containing PAHs, and specific indicator compounds such as steranes and hopanes, which are highly resistant to weathering. With the increase in the number of target analytes comes an immense amount of information with which to characterize hydrocarbon releases for the purpose of making comparisons, establishing sources, and apportioning liability.

The practice of environmental forensics requires environmental professionals to think about environmental issues from a different perspective, and creatively and logically apply established scientific tools to elucidate the relevant technical and legal issues in a specific case. These tools, in conjunction with site-specific historical, geological, and hydrological data, can then be forged into a technically defensible opinion to help resolve environmental disputes.

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Environmental Forensic Tools and Applications

TOOL	POTENTIAL APPLICATIONS
Petroleum Hydrocarbon Fingerprinting	Source identification, source apportionment, release timing.
Isotope Analysis	Source identification, source apportionment, dating of material.
Groundwater Modeling	Constrain timing of release, source identification.
Analysis of Gasoline Additives	Source identification, timing of release.
Statistical Analyses/Data Visualization	Digest or present large amounts of information, source identification, preparation of exhibits.
Historical Research	Add or eliminate Potentially Responsible Parties.
Dioxins/Furans & Polychlorinated Biphenyls (PCBs)	Source identification, source apportionment, dating.

Transport Modeling as a Forensic Tool

Properly applied, predictive models can help define release sources and timing.

Contaminant transport modeling typically has been used by environmental professionals to predict exposure concentrations for risk assessments, evaluate remedial alternatives, and design remediation systems. However, the key attributes of contaminant transport models – that is, the use of mathematics to simulate a physical problem and the ability to examine "what if" questions, are ideally suited to addressing forensic issues. Consequently, contaminant transport models are being increasingly used to solve a wide range of forensic problems – the most frequent being release timing and source identification/contribution.

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Determining the approximate date or time frame of an environmental release can be an important issue for insurance cost recovery claims, and for determining liability or allocating costs, if a property had multiple owners over time. For a groundwater contamination problem, the simplest way of determining the timing of a release consists of calculating a travel time from a source area to a designated point (*e.g.*, a monitoring well) using a contaminant's transport velocity. A contaminant's transport velocity can be estimated using a variety of methods ranging from analysis of the site's hydrogeologic characteristics to conducting tracer studies. The contaminant's release timing can be determined from the transport velocity and the date when contaminants first reached the designated point, or from the variation in extent of a contaminant plume over time. In complex settings, such as highly heterogeneous geologic deposits, two- or three-dimensional contaminant transport models may be necessary to determine the release date.

Release timing also can be determined using concentrations measured in soils. For example, the contaminant mass lost due to leaching, volatilization, and degradation from a contaminant source present in the unsaturated zone can be quantified and used to constrain a mass balance model. The model then can be used to estimate the release date, if the starting concentrations in the source material are available (*e.g.*, from a plant's process history) or readily obtainable from the literature (*e.g.*, the range of benzene concentrations in gasoline is well documented).

Contaminant transport models also are very useful in identifying the possible location of "new," yet undefined sources, and defining the contribution from a given source in a multiple-source setting. For example, consider the concentration measurements at monitoring wells A, B, and C shown on the figure. A contaminant plume is clearly emanating from the underground storage tank (UST). The concentration measured at point C could either be a result of: 1) lateral spreading of the plume that originates at the UST, or 2) a plume emanating from a separate source(s) in the tank farm and/or the manufacturing building. A field program could be designed to identify the source of the contamination measured at well C. However, a more cost-effective approach would be to "calibrate" a contaminant transport model using the concentrations measured at wells A and B, and then determine whether the concentrations measured at well C could be attributable to the UST. In addition, the calibrated model then could be used to determine which of the two other potential sources upgradient of well C would most likely result in the concentrations measured at well C. In this example, modeling indicates that concentrations at well C are most likely originating at the tank farm. Such analyses are useful not only for designing cost-effective field investigation programs, but also for apportioning contribution from multiple sources, often a key issue for allocating costs at Superfund sites.

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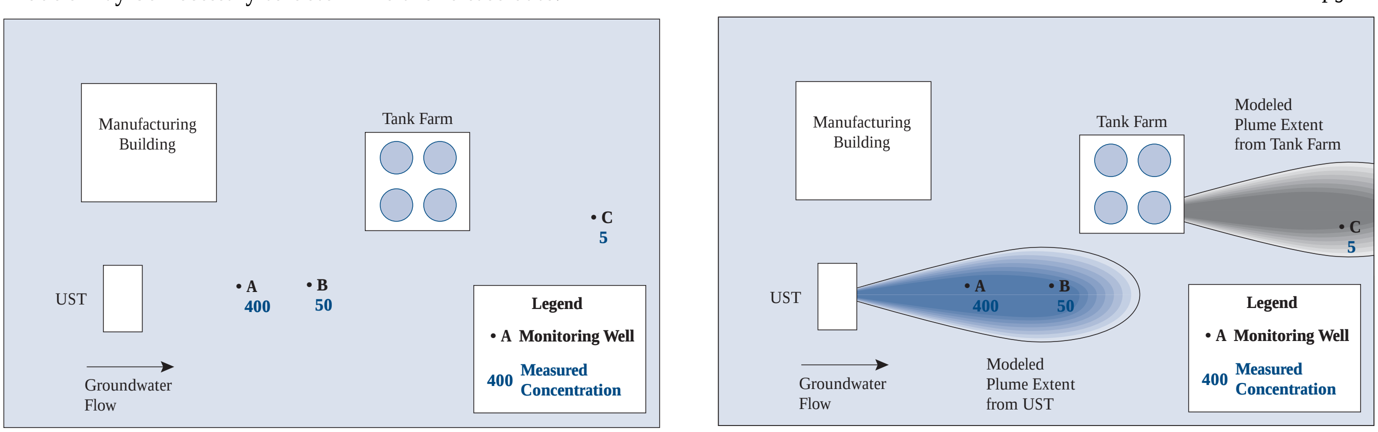

Contaminant fate and transport modeling can be used to establish the source of a particular contaminant plume.

Non-petroleum Forensic Chemistry

Previously the domain of petroleum chemists, advanced analytical methods are enjoying expanded application.

Forensic chemistry studies typically are designed to discern unique chemical signatures of a contaminant attributable to a specific source, for the purpose of determining liability (Wait, 1999). Petroleum hydrocarbon characterization (see related article) is one example of forensic analysis. Recently, however, detailed analyses of many other contaminants (*e.g.*, chlorinated solvents such as TCE, polychlorinated biphenyls (PCBs), and polychlorinated dibenzodioxins and furans (PCDD/Fs)) also can provide clues as to their origins.

Recognizing the utility of such analyses, the U.S. EPA has started to develop and promulgate GC/MS methods designed to analyze for certain PCB congeners.

Regulatory analytical chemistry methods of the 1980s focused on developing accurate identification and quantification of compounds that were selected, in part, by their prevalence in the environment and perceived potential to impact public health. In fact, until recently, PCBs have been most often analyzed and reported as a total Aroclor® value. (Aroclor® is the trade name under which various PCB mixtures were marketed. Congeners are the specific chemicals that make up the PCB and/or PCDD/F mixtures.) This total Aroclor® analysis was of some benefit to the forensic chemist in discerning the source of the PCBs, if they were not degraded, and if the types of PCBs from multiple sources were significantly dissimilar. Thus, these analytical methods had limited value for forensic studies of source and fate, because they failed to distinguish among the specific discrete chemicals that comprise the PCBs and PCDD/Fs.

PCBs and PCDD/Fs are of particular interest to regulators due to their potential toxicity. Prior to the development of high resolution gas chromatography (GC) with high resolution mass spectroscopy (MS), PCDD/Fs were difficult to identify and quantify at low concentrations. New GC/MS methods have been developed to analyze for specific PCB and PCDD/Fs congeners that are of particular concern for public health. With the advent of high resolution capillary GC columns, resolution and identification of PCB congeners in environmental samples has become a reality (Shifrin and Toole, 1998). Recognizing the utility of such analyses, the U.S. EPA has started to develop and promulgate GC/MS methods designed to analyze for certain PCB congeners (*e.g.*, RCRA Method 8082 and drinking water Method 1668).

Although these analytical methods were developed as a result of concerns about differential congener toxicity, they provide fruitful information for forensic investigations as well. One example of using congener distributions as a fingerprint tool is described in a study conducted by Huntley, *et al*. (1998) to discern sources of PCDD/Fs in Newark Bay estuary sediments. High resolution GC/MS was used to analyze seventeen specific PCDD/F congeners. In addition, statistical analysis, isotope dating techniques, and historical information were employed. The researchers found three source-specific PCDD/F fingerprint patterns consistent with combustion sources, sewage sludge, and PCBs. In a similar study, Hwang, *et al.* (1993) used a PCB congener pattern of a known point source of contamination and compared it to the pattern found in a variety of contaminated fish collected in the St. Lawrence River. The PCB congener patterns found in certain fish collected near industries on the river were correlatable to contamination at those sites.

In the future, as PCB and PCDD/F congener analyses continue to evolve, they will no doubt be used in conjunction with multivariate statistical assessment as important tools for discerning the source(s) of these constituents.

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Huntley, S.L., H. Carlson-Lynch, G.W. Johnson, D.J. Pastenbach, and B.L. Finley. 1998. Identification of historical PCDD/F sources in Newark Bay Estuary subsurface sediments using polytopic vector analysis and radioisotope dating techniques. *Chemosphere* 36:1167-1185.

Hwang, S., L. J. Gensberg, E.F. Fitzgerald, P.M. Herzfeld, and B. Bush. 1993. Fingerprinting sources of contamination: Statistical techniques for identifying point sources of PCBs. *J. Occup. Med. Toxicol* 2:365-382.

Shifrin, N.S. and A.P. Toole. 1998. Historical perspectives on PCBs. *Eng. Sci*. 15:247-257.

Wait, A.D. 1999. Evolution of organic analytical methods in environmental forensic chemistry. *International Journal of Environmental Forensics* 1(1):68-86. http://www.aehs.com/IJEF.

BY THE WAY...

U.S. EPA has released new draft cancer risk assessment guidelines that include five classification categories assessing the likelihood that a chemical will cause cancer in humans.

Source: U.S. EPA, Risk Assessment Forum. 1999. *Guidelines for Carcinogen Risk Assessment*. NCEA-F-0644. July.

What's New at Gradient

Gradient Completes Management Buyout

Gradient recently withdrew from the IT Group organization to once again become a private consulting firm. Going forward, little change will be noticed – our staff, technical skills, markets served, and focus on high quality science and client service will continue. In addition, through a "marketing alliance" with the IT Group, Gradient will be able to conveniently provide field and remediation services *via* its former parent organization.

Gradient Welcomes Dr. Lorenz Rhomberg

Dr. Lorenz R. Rhomberg has joined Gradient as a Program Manager. Dr. Rhomberg is an expert in quantitative risk assessment, including pharmacokinetic modeling, and probabilistic methods, with special experience in health effects of chlorinated solvents and endocrine active compounds. He earned his Ph.D. in population biology from the State University of New York at Stony Brook and his B.S. in biology from Queen's University in Ontario. Before coming to Gradient, he held a position at the Harvard School of Public Health, where he will continue a relationship.

Dr. A. Dallas Wait Joins Editorial Board

Gradient Principal, Dr. A. Dallas Wait, was recently invited to join the Editorial Advisory Board for the *International Journal of Environmental Forensics*.

Recent and Upcoming Presentations

Amherst, MA. October 19. A. Dallas Wait. Moderator for Risk Session at the 15th Annual International "Conference on Contaminated Soils & Waters," University of Massachusetts.

Boston, MA. October 28. A. Dallas Wait. "Forensic Chemistry: Tools for Discerning Site Liability," at the Technology and Information Exchange Breakfast Seminar sponsored by IT Corporation.

Philadelphia, PA. November 16, 17. Richard Blanchet. "Reducing Uncertainty in Ecological Risk Assessments: Application of Inorganic Uptake Factors from Soil to Biota" and "Aggregate Exposure Model for Pesticide Drift," poster presentations at the Society of Environmental Toxicology and Chemistry 20th Annual Meeting.

Atlanta, GA. December 5-8. Lorenz Rhomberg. "Framing Exposure Issues" and "Cross-species and Cross-route Comparisons of Acute Lethal Doses: Further Results of Analysis on a Large Database," at Society for Risk Analysis Annual Meeting.

Recent Articles

Abernathy, C.O., Y.P. Liu, D. Longfellow, H.V. Aposhian, B. Beck, B. Fowler, R. Goyer, R. Menzer, T. Rossman, C. Thompson, and M. Waalkes. 1999. Arsenic: health effects, mechanisms of actions, and research issues. *Environmental Health Perspectives* 107(7):593-597.

Bowers, T.S. 1999. The concentration term and derivation of cleanup goals using probabilistic risk assessment. *Human and Ecological Risk Assessment* 5(4):809-821.

Wait, A.D. and L.L. Cook. 1999. Opportunities in environmental forensic chemistry analysis. *Environmental Testing & Analysis* 8(4):31-32. July/August.

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Transport Modeling as a Forensic Tool

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All reviewers of modeling results (*e.g.*, attorneys, regulators, and industry) need to understand that models do not necessarily yield unique solutions, and that they have inherent simplifying assumptions and uncertainties. A good modeling application explains the assumptions and uncertainties and discusses the sensitivity of modeling results to input data. Nonetheless, contaminant transport modeling is clearly a powerful forensic tool that can be used to support decisions involving subsurface contamination.

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Guest Editorial: A Lawyer's Perspective on the Use of Environmental Forensic Tools in Court

The ultimate proving ground for environmental forensic efforts is often the courtroom.

Environmental forensics, broadly defined, has become an inevitable part of all but the simplest legal cases concerning liability and allocation of costs among parties responsible for environmental contamination. Source identification, travel time, direction and extent of migration, potential pathways for and duration of exposure, and relative contributions of multiple overlapping releases are only a few of the issues for which attorneys commonly retain chemists, hydrogeologists, and other scientists to develop and defend expert opinions.

By itself, one expert's opinion on any of these issues will not decide a case. First, although not as immutable as the laws of physics, a basic rule in litigation is that for every one expert there will be an opposing, if unequal, expert. Second, the forensic tools available from the environmental sciences cannot provide the same certainty, for example, as human fingerprinting or even DNA profiling. Third, environmental disciplines are interdependent. To be of use, an opinion as to the chemistry of a groundwater or soil sample must be joined, for example, to opinions and other evidence concerning the dynamics of the environment from which it was taken.

> *...although not as immutable as the laws of physics, a basic rule in litigation is that for every one expert, there will be an opposing, if unequal, expert.*

Opinions based on environmental forensic evidence are most compelling when they are well integrated into a clear conceptual model for the case. From the scientists' perspective, this means defining the legal problem in a way that it can be resolved legitimately and persuasively using the right combination of available resources. It also means working with the attorneys to ensure that the questions that the experts can answer fit logically within the factual narrative ultimately presented as the theory of the case. Regardless of the intended audience, the ideal is to lend the aura of scientific certainty to a conclusion for which agency staff, opposing counsel, a judge or a jury already has been prepared to believe as a matter of common sense.

Although the goal is to suggest an inescapable conclusion, the objective should not be confused with the process. The best forensic experts will see in a site not its predefined limits, but its opportunities. They will relish the challenge of finding a new perspective on what at first appears to be unambiguous and unremarkable. They also will know the latest techniques, including their purposes and limitations, and will not make one method fit every case.

Environmental forensics are not inexpensive, and the cost of misunderstanding them can be even higher. Knowing when to test or model and how, and when to leave well enough alone, can be critical. The best results can be obtained only through collaboration between counsel who understand the science, and experts who can and will adapt current scientific methods to solve practical legal questions.

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In the next issue:

Overview: Appropriate Use of Scientific Information

The Role of Epidemiology in Site Decision-making

Biomonitoring in Risk Management

Guest Editorial: The Growing Marginalization of Science

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