ENVIRONMENTAL PERSPECTIVES

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Navigating the Regulatory and Management Uncertainty Underlying Hydraulic Fracturing

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Hydraulic fracturing (often called "fracking") of oil and gas wells has been understood and used for more than 60 years. Fracking is a stimulation operation in which fluids are pumped at sufficiently high pressure through a well casing to create new fractures in rock or to open existing natural fractures in low permeability formations, so that greater volumes of oil or natural gas can be produced. This technique has led to the development of unconventional gas reservoirs and reassessment of the recoverable reserves of natural gas in the U.S. (Figure 1).

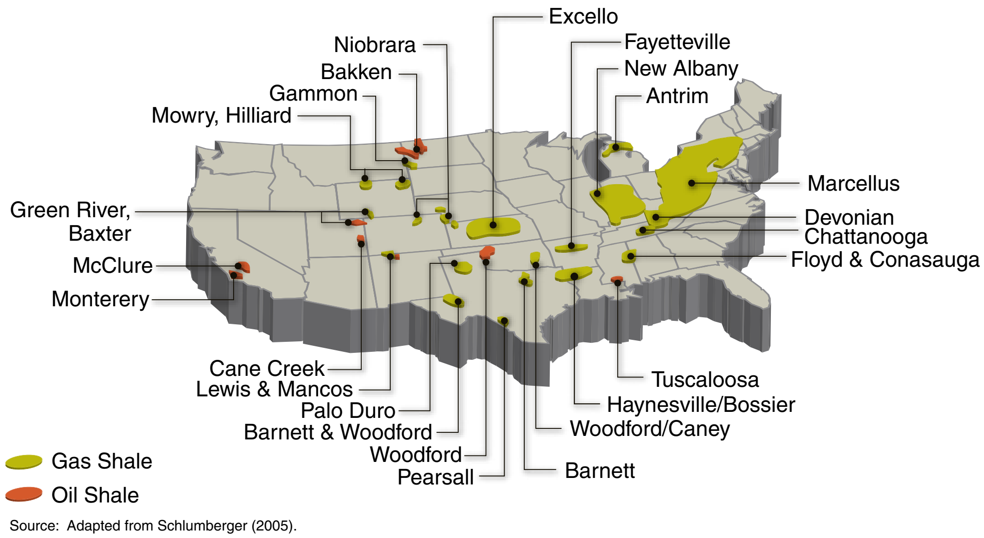

Figure 1.
Locations of oil and gas shale basins in the United States

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With increased demand for clean burning gas, the complex and highly visible fracking operations (see typical hydraulic fracturing site layout in Figure 2) started to approach residential and ecologically sensitive areas. As a result, citizens, environmental groups, regulatory agencies, and state and federal legislatures raised concerns regarding possible health and environmental effects associated with fracking chemicals and their potential for leakage into drinking water aquifers, or discharge after use to environments with sensitive habitats. Concerns have also arisen about opening up pathways of migration of natural gas itself to drinking water wells.

Figure 2.
Typical hydraulic fracturing site layout (PIOGA 2011)

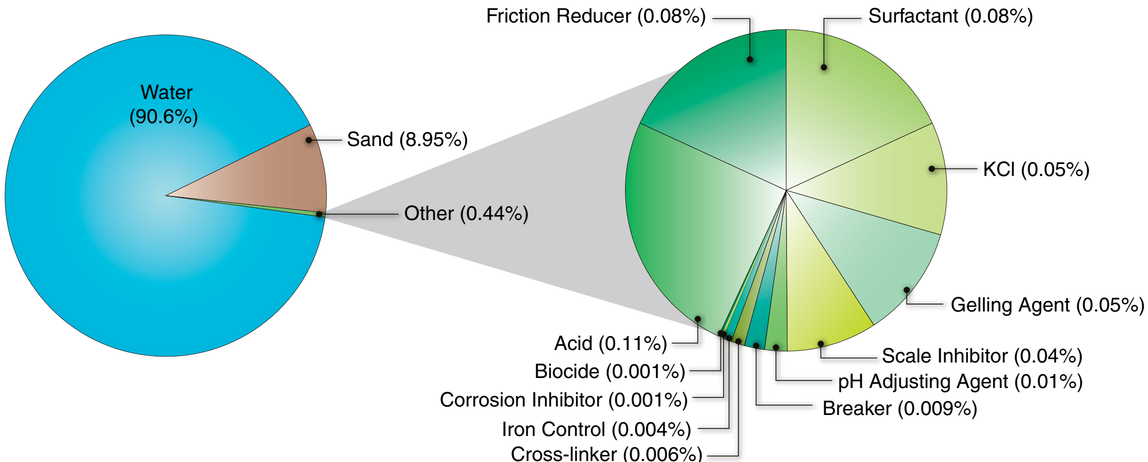
In this issue, we provide information on fracking operations and the fluids used in the process, discuss current environmental concerns surrounding hydraulic fracturing, and discuss potential strategies to understand and mitigate risk from hydraulic fracturing.

How Does Fracking Work and What Are Fracking Fluids?

In the process of hydraulic fracturing, sand or tiny ceramic spheres are mixed with a viscous fluid to form a sand-fluid mixture called a "slurry." This slurry is pumped into the gas-bearing formation, with the slurry fluid pressure increased until the pressure overcomes the weight of the earth above the formation and the strength of the rock formation. This results in rock cracking or fracturing. Once the rock is fractured, the slurry pressure is reduced so that the gas in the rock can flow through the newly-formed fractures and back into the well.

The weight of the earth above the rock formations tends to cause the fractures to close up. The purpose of the sand or minute ceramic spheres is to "prop" the fracture open so that gas can continue flowing through the fracture; thus, the sand or spheres are referred to as "proppants." After fracturing, large quantities of fracking fluid containing residual chemicals are recovered, handled, and disposed. There are several alternatives for handling these flowback fracking fluids: local subsurface disposal, offsite disposal, or reuse. While reusing fluids may be attractive to reduce the total volume of fluids needed, these fluids eventually will need to be disposed.

Typical hydraulic fracturing and flowback slurry is about 99% water and sand/micro-spheres, as shown schematically in Figure 3.



Source: Adapted from Authur et al. (2009).

Figure 3.
Composition of fracturing fluid

The remainder of the mixture consists of additives. The functional types of additives and their purposes include the following (Halliburton 2011):

- Gelling agents and cross-linkers, which provide viscosity to the water to carry the proppants. Example chemicals include guar gum (liquid thickener). In some cases and because of operational needs and cost reduction considerations related to the cost of transportation of gelling agents to a fracking site, diesel fuel is mixed with the gelling agent instead of water (Halliburton 2002, as cited in U.S. EPA 2004). Gelling agents dissolve more effectively in diesel than in water and therefore the total volume of the gelling agent (and the cost of transportation) is reduced.[1]
- Breakers and friction reducers to release the proppants after fracturing and reduce viscosity to enhance flowback. Example of chemicals in this category include hydrotreated light petroleum distillate, hemicellulase enzyme, and carbohydrates.
- Potassium chloride (KCl) to stabilize any clay in the formation.
- Acids (such as hydrochloric acid, acetic anhydride or acetic acid) to clean up residual cement and other debris in the perforations and around the well.

1 Note that all fracking fluid constituents were exempt from regulation until 2005, when the exemption for diesel was discontinued. Congress allowed the continuation of the exemption for all other constituents (U.S. Congressional Letter 2011).

- Biocides to prevent bacterial corrosion. Examples of biocides include tributyl tetradecyl phosphonium chloride.
- Scale inhibitors, like ammonium chloride, prevent scale and particulate buildup that may plug fractures.
- Corrosion inhibitors such as propargyl alcohol and methanol to prevent general corrosion of wellbore casing and tubing.
- Oil, gas, and water from drilling and production operations may also contain naturally occurring radioactive materials in production waters, called "NORM". NORM contains the element radium, a radioactive decay product of naturally occurring uranium and thorium.

The volume of water and other fluids in a horizontal fracture job might range from 20,000 to 50,000 barrels. Multiple hydraulic fractures in such long horizontal wells may require as much as 500,000 to 1 million barrels of fracking fluids (Gaudlip et al. 2008.) Because these large volumes are injected into the ground, there is a public concern for contact with drinking water supplies and other environmental media.

Environmental Concerns and Recent Regulatory Actions

Releases of fracking fluids from holding ponds and the resulting groundwater contamination have supported citizen concerns about fracking operations and the risk of exposure to chemicals that might be present in some fluids (e.g., Plagianos 2010). Because the U.S. Environmental Protection Agency (EPA) classifies benzene as a human carcinogen, exposure to BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) is of particular concern (ATSDR 2007). In addition, the radioactive materials that may be contained in fracking fluids have been reported to increase the risk of cancers (U.S. EPA 2011). Along with the potential risks associated with transport and exposure to fracking fluids at the surface, drilling operations and well construction design came under scrutiny as potential causes of subsurface migration of natural gas from deeper formations to shallower drinking water aquifers and residential water wells. Recently, in one particular natural gas field in Texas, EPA ordered the operator to investigate the structural integrity of one of its natural gas wells to determine if it is the source of asserted natural gas contamination of residential water wells. (Knepp 2010).

Beckwith (2010) lists the following actions that have been taken in response to environmental concerns and natural gas impacts to residential water wells from fracking operations:

- In mid-September 2010, Wyoming became the first state in the U.S. to require public disclosure of all chemicals used in fracturing.

- Until 2010, Pennsylvania allowed disposal of recovered fracturing fluids into the Commonwealth's waters without any treatment. As recently as January 2011, the regulations have changed. The new regulations require that developers treat produced water down to 500 mg/L total dissolved solids (TDS). This is likely to seriously limit the industry's ability to operate economically (PRNewswire 2010).
- On December 13, 2010, New York Governor David Paterson imposed a moratorium on horizontal drilling until May 15, 2011 (Schenkel 2010).
- The U.S. House of Representatives Committee on Energy and Commerce continues to examine the potential environmental impact of hydraulic fracturing.
- Court cases, such as the case Independent Petroleum Association of America, et al. v. EPA in the DC Circuit, seek clarification as to whether EPA can regulate the injection of diesel fuels and other materials as part of the fracking process.
- EPA is currently designing a study to examine the possible relationship between hydraulic fracturing fluids and the quality of drinking water (http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/) although according to EPA, funding constraints limit the scope of such a fracking study.
- Representative Edward Markey (D-Mass) requested immediate action by EPA focusing on the potential of radium contamination of drinking water sources from gas extraction by fracking and insufficient treatment of radium-contaminated wastes (Dye 2011).

Much of the environmental concern about fracking may be addressed through well-designed and well-run operations that minimize the potential for contamination. Successful gas and oil production can coexist if care is taken in managing potential environmental issues.

How Can Health and Environmental Risks Be Understood and Mitigated?

Concerns about fracking operations have been investigated in order to understand the actual versus the perceived risks. For example, the Pennsylvania Department of Environmental Protection conducted a study of seven Pennsylvania rivers located near fracking operations and found water radiation levels to be at or below normal, naturally occurring background levels (Hopey 2011). This study addressed the concern about radioactive materials being present in fracking fluids used near those rivers, and showed that the presence of fracking operations in an area does not equate to environmental contamination.

Similar to the concern about radioactive materials and fracking fluids, the concern about natural gas migrating into residential water wells as a result of hydrofracking operations has to be studied and understood. This is because natural gas occurs normally in many drinking water wells in states like Pennsylvania and New York, for example. Indeed, in a study (by Exponent and others) to identify sources of natural gas in north Central Pennsylvania water wells, native natural gas was reported to be present in several residential properties in towns far from any hydrofracking operations.

Given the increasing public concern and inherent risks of the fracking process, it is important to consider adopting an operations program that minimizes the potential for the loss of fracking fluids, manage any loss that might occur, create a comprehensive strategy for treating waste fluids, and limit risks to the environment and the public.

Drilling Practices

Prudent drilling practices and thoughtful design of the well completion and hydraulic fracturing procedures can mitigate or minimize the risks of fracturing fluid migration. Preventing fluids from exiting the wellbore requires the following:

- Well-designed and implemented cement jobs to prevent channeling and voids in the cement
- Consideration of using cement bond logs to check the quality of the cement job, when necessary
- Selection of casing, tubing, and completion equipment materials to mitigate the risk of stress cracking and corrosion failures in gas environments
- Use of tight threaded gas connections to prevent seepage of either gas or fracturing fluids.

The risks associated with fracture size and geometry can be addressed through careful formation rock characterization and testing, geological characterization and logging of the region under development, modeling of the fracture geometry, and of course, control of the pumping rate of fluids.

Identification of Natural Gas in Residential Water Wells

When evidence of contamination of residential water wells with natural gas is presented, a prompt and comprehensive investigation of the source of natural gas is imperative. This investigation will determine whether native shallow gas was naturally occurring prior to the fracking operations, or if natural gas pathways to the well resulted from fracking operations. These investigations are commonly conducted using carbon and hydrogen isotope analysis. For example, the hydrogen composition in landfill gas is isotopically lighter than that of thermogenic gases (natural gas and coal bed gas). Exponent's Environmental Forensic short notes provided details on natural gas geochemistry and the isotope analysis methods that can be used to determine the origin of the gas.

Waste Management

Many of the concerns regarding fracking materials focus on the disposition of the waste materials. Current regulatory activity is focused on restricting how and where fracking waste is disposed. With a comprehensive understanding of the chemical properties and toxicity of the fluid components, a waste treatment and disposal plan can be developed to ensure that the waste does not impact the environment. Indeed, "EPA has reviewed and approved innovative coal bed methane (CBM) wastewater treatment residual disposal options that allow injection into Class II wells, creating better economic scenarios for creating cleaner water for surface discharge or aquifer storage" (U.S. EPA 2008).[2]

Risk and Exposure Reduction

The potential risks posed by fracking fluids that may enter the environment (i.e., drinking water, wetlands, wildlife) can be evaluated using risk assessment approaches. Human health and ecological risk assessments combine the chemical concentration and toxicity with the potential for exposure to the contaminated medium (e.g., drinking water, surface water) to arrive at risk estimates. By focusing on the exposure side of the risk equation, wastewater generated from the fracking process may be treated between the source and receptor, or may be removed to eliminate the possibility of exposure. Also, it may be possible to identify less toxic substitutions for particularly toxic constituents. Solutions might also focus on a combination of minimizing exposure and reducing toxicity.

With increased demand for clean burning gas, the use of hydraulic fracturing will continue to expand in many areas of the country. While growing environmental concerns about fracking fluids and related chemicals are likely to invite increasingly stringent regulation, there are steps that can be taken to manage the risks in order to continue operations at active wells.

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2 Until 2010, Pennsylvania allowed disposal of recovered fracturing fluids into the Commonwealth's waters with limited treatment. As of January 2011, the regulations have changed, and the new regulation requires developers to treat produced water down to 500 mg/L TDS.

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References

Arthur, JD, Bohm, B, Coughlin BJ, Layne M. 2009. Evaluating implications of hydraulic fracturing in shale gas reservoirs. Society of Petroleum Engineers. SPE 121038.

ATSDR. 2007. Toxicological profile for benzene. Available at: http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=40&tid=14. U.S. Department Of Health And Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

Beckwith R. 2010. Hydraulic fracturing: the fuss, the facts, the future. Journal of Petroleum Technology, 62(12): 34–41.

Dye J. 2011. House democrat pushes EPA to up fracking oversight. Environmental Law 360. February 28, 2011.

Gaudlip AW, Oaugh LO, Hayes TD. "Marcellus Shale Water Management Challenges in Pennsylvania," SPE 119898, presented at 2008 SPE Shale Gas Production Conference, November 16–18, 2008, Fort Worth, TX.

Halliburton. 2011. Hydraulic Fracturing 101. Available at: http://www.halliburton.com/public/projects/pubsdata/Hydraulic_Fracturing/index.html

Hopey D. 2011. High radioactivity from Marcellus not found in 7 Pa. Rivers. Pittsburgh Post-Gazette. March, 7, 2011.

Knepp R. 2010. EPA orders drilling company to clean up water at Barnett Shale site. Houston Energy Industry Examiner, December 8, 2010. Available at: http://www.examiner.com/energy-industry-in-houston/epa-orders-drilling-company-to-clean-up-water-at-barnett-shale-site)

PIOGA. The facts about hydraulic fracturing/well stimulation. Pennsylvania Independent Oil & Gas Association. Accessed March 1, 2011. Available at: http://www.pioga.org/publication_files/hydraulic-fracturing-fact-sheet.pdf

Plagianos I. 2010. Drilling for Trouble? The American Lawyer.Com. December 1, 2010. Available at: http://www.law.com/jsp/tal/PubArticleTAL.jsp?id=1202475021788&slreturn=1&hbxlogin=1

PRNewswire. 2010. Governor Rendell Praises Regulatory Panel Vote Protecting PA's Stream, Rivers from Drilling Wastewater, June 17, 2010. Available at: http://www.prnewswire.com/news-releases/governor-rendell-praises-regulatory-panel-vote-protecting-pas-stream-rivers-from-drilling-wastewater-96599309.html

Schenkel A. Paterson's veto is the latest twist in the fracking saga. Available at: http://www.mnn.com/earth-matters/energy/blogs/patersons-veto-is-the-latest-twist-in-the-fracking-saga.

U.S. EPA. 2004. Evaluation of impacts to underground sources of drinking water by hydraulic fracturing of coalbed methane reservoirs. EPA 816-R-04-003. U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 2008. Sector Strategies - An Assessment of the Environmental Implications of Oil and Gas Production: A Regional Case Study. Working Draft. U.S. Environmental Protection Agency, Washington, DC. Available at: http://www.epa.gov/sectors/pdf/oil-gas-report.pdf

U.S. EPA. 2011. Radium fact sheet. Available at: http://www.epa.gov/rpdweb00/radionuclides/radium.html#affecthealth. Accessed March 15, 2011. U.S. Environmental Protection Agency, Washington, DC.

Next Issue—
Environmental Liability of U.S. Clients from Operations and Legacy Sites Outside the U.S.: Case Studies

Gary Bigham, L.G., Charles Menzie, Ph.D., and Pieter Booth

What do unpredictable regulations, an agitated public, and complex political agendas have in common? Answer, they all pose significant challenges to multi-national corporations with legacy assets or operations around the world. These legacy assets and/or ongoing operations may have historically been developed under different regulatory frameworks among countries, creating complex potential environmental liabilities. Around the world there has been a notable increase in environmental disputes, some of which have come before the International Court of Justice and the International Chamber of Commerce. Other cases have been filed in the United States or within the respective countries. While some cases represent disputes between countries, many have involved damage claims against multi-national corporations. These claims are driven by increases in environmental regulations and directives that are highly variable among countries. The complexity of the resulting litigation is a result of this variable and changing landscape of environmental regulation. In some regions, such as the European Union, there has been very active development of environmental directives. The environmental regulatory frameworks in other developed industrial nations (Australia, Canada, New Zealand, Japan, etc.) tend to be similar to those in the U.S. and EU and, like the EU, have low levels of environmental litigation. However, elsewhere in the less developed world, environmental liability is far less predictable. Many countries have adopted environmental regulations based on those from the U.S. and other industrialized nations, but their application and enforcement can be inconsistent with the intent of the original U.S. regulations. Through case studies we examine the challenges presented by international environmental liability and offer strategies for approaching these often unpredictable cases.

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New Faces

Donald G. Patterson, Jr., Ph.D.
Principal— Environmental Sciences Practice

Dr. Patterson's technical expertise includes analytical chemistry, data quality, human biomonitoring, and chemical exposure assessment. He is world renowned for his research in the detection and quantification of persistent and non-persistent organic pollutants and their assessment in the human body. Dr. Patterson was a member of the Senior Biomedical Research Service in the Organic Analytical Toxicology Branch, National Center for Environmental Health at the Centers for Disease Control and Prevention (CDC), where he led a group of research scientists for 29 years, developing state-of-the-art analytical methods for measuring environmental chemicals and their metabolites in human tissues.

Dr. Patterson specializes in human exposure assessment and internal dose measurements of environmental pollutants using state-of-the-art analytical techniques. These methods have been applied in large-scale epidemiologic studies such as the U.S. Air Force operation Ranch Hand Vietnam Veteran Agent Orange Study; Seveso, Italy, dioxin exposure study; NIOSH worker dioxin exposure study; and the biannual National Health and Nutrition Examination Survey (NHANES) studies, designed to establish U.S. population reference ranges for many environmental chemicals. He holds a B.A. in Chemistry from the University of Northern Colorado, and a Ph.D. in Organic Chemistry from Arizona State University.

Carlo Monti, Ph.D.
Senior Managing Scientist— Environmental Sciences Practice

Dr. Monti specializes in the evaluation of transport, fate, and effects of contaminants in aquatic habitats, soil, sediment, and groundwater. He has managed and been the principal investigator of field, laboratory, and theoretical assessments of a wide variety of contaminants in lakes, rivers, estuarine waters, ocean waters, and groundwater. Dr. Monti has also directed ecological risk assessments, cost allocation studies, and Environmental Liability assessments for sites involving soils, sediments, and waters contaminated with dioxin, PCBs, DDT, mercury, petroleum hydrocarbons, solvents, and other contaminants. He has conducted fate and transport modeling at the basin level in a variety of river systems. Dr. Monti is an expert in environmental forensics. He has also conducted environmental due diligence assessments at a variety of industrial facilities in Europe, Asia, and Central and South America.

Dr. Monti holds a B.S. in Biology from Milano State University, and a Ph.D. in Environmental Sciences from the Italian Institute of Hydrobiology.

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Sungwoo Ahn, Ph.D.
Senior Scientist—Environmental Sciences Practice

Dr. Ahn specializes in the transport and fate of hydrophobic organic contaminants including PAHs, PCBs, and polybrominated diphenyl ethers (PBDEs), and their bioavailability. He also has expertise in the environmental behavior of nanomaterials. He is knowledgeable in the use of a variety of laboratory analytical methods including gas chromatography (GC) and mass spectrometry (GC/MS), transmission electron microscopy (TEM), scanning electron microscopy (SEM), x-ray photoelectron spectroscopy (XPS), and x-ray diffraction (XRD).

Before joining Exponent, Dr. Ahn worked as a postdoctoral scholar at Stanford University, where he conducted research on the degradation of flame retardant PBDEs by various forms of nano-scale zerovalent iron (nZVI). Dr. Ahn studied the reaction of kinetics and the degradation pathways of PBDEs with positional preference in the debromination. As a part of the research, he synthesized the nanoparticle, as well as its catalyzed and carbon supported particles, in the laboratory, and characterized them using analytical tools such as TEM, SEM, XPS, and XRD.

Dr. Ahn holds both a B.S. and an M.S. in Chemical Engineering from Yonsei University in South Korea. In addition, he earned an M.S. and a Ph.D. in Civil and Environmental Engineering from Stanford University.

Ronald J. Breitmeyer
Senior Associate—Environmental Sciences Practice

Mr. Breitmeyer is an engineering hydrogeologist specializing in the study of multi-phase flow in engineered and natural porous materials. He has conducted research on liquid flow through municipal solid waste landfills and on thermal convection in laboratory-scale porous media. He has also performed hydrologic analysis for landfill cover design. He has designed instrumentation for monitoring in-situ moisture content in solid waste or other geomaterials and has experience in the programming and operation of automated field environmental data collection systems. Mr. Breitmeyer has designed and fabricated laboratory equipment for geotechnical and hydrologic analysis of solid waste and other compressible porous materials. He is currently completing his Ph.D. in geological engineering from the University of Wisconsin-Madison, expected to be completed in May 2011.

Mr. Breitmeyer holds both an M.S. and a B.S. in Hydrogeology. Both degrees are from the University of Nevada, Reno. His bachelor's degree was achieved with high distinction.

Jane P. Staveley
Senior Managing Scientist—EcoSciences Practice

Ms. Staveley has more than 30 years of experience in environmental toxicology and ecological risk assessment, working with clients in both the public and private sector on a broad variety of environmental issues. She has extensive experience in ecotoxicology testing and risk assessment for pesticides, industrial chemicals, pharmaceuticals, and effluents, and is well versed in testing guidelines developed under a variety of worldwide regulatory programs.

With significant volunteer service to several scientific organizations, Ms. Staveley is a recognized leader and consensus builder in the professional scientific community. She is the current Immediate Past President of the Society of Environmental Toxicology and Chemistry (SETAC). In this role, she was invited to moderate a recent science briefing for U.S. Congress staff on "Pharmaceuticals in Our Water: Concerns and Responses." She also was part of the delegation representing SETAC at the second session of the International Conference on Chemicals Management to discuss the Strategic Approach to International Chemicals Management (SAICM). Ms. Staveley holds a B.S. in Biology from the College of William and Mary, and an M.S.P.H. in Environmental Chemistry and Biology from the University of North Carolina at Chapel Hill.

Mr. Wayman Turner
Senior Scientist—Environmental Sciences Practice

Mr. Turner's technical expertise includes clinical/nutritional biochemistry, bioanalytical chemistry, analytical chemistry, laboratory data handling and quality control/quality assurance, specimen collection and storage and human biomonitoring and chemical exposure assessment. He is recognized worldwide for his research in the measurement of persistent organic pollutants and their assessment in the human body.

Prior to joining Exponent, Mr. Turner served for 38 years in a variety of positions at the Centers for Disease Control and Prevention (CDC), including Chief of the National Health and Nutritional Examination Survey (NHANES) Laboratory in the Nutritional Biochemistry Branch, and as Chief of the Bioanalytical Research Laboratory in the Analytical Biochemistry Branch. For the past 23 years Mr. Turner was Chief of the Dioxin and Persistent Organic Pollutants (DOXPOPs) Laboratory in the Organic Analytical Toxicology Branch, National Center for Environmental Health (NCEH). He directed the scientists in the DOXPOPs Laboratory in the development and application of state-of-the-art analytical methods for human exposure assessment and internal dose measurements of persistent environmental pollutants using high-resolution gas chromatography/isotope-dilution high-resolution mass spectrometry techniques. Mr. Turner holds a B.S. in Biology from Georgia State College, and an M.S. in Microbiology from Georgia State University.

Publications

Booth P, **Salatas J**, Jawetz S. Restoring the Great Lakes: The Great Lakes Legacy Act, Great Lakes Restoration Initiative, and NRDA. ABA Newsletter on Superfund and Natural Resource Damages Litigation 2010; 6(1).

Diamond ML, Gandhi N, Adams WJ, Atheron J, Bhavsar SP, Bulle C, Campbell PGC, Dubreuil A, **Fairbrother A**, Farley K, Green A, Guinee J, Hauschild MZ, Huijbregts MAJ, Humbert S, Jensen KS, Jolliet O, Margni M, McGeer JC, Peignenburg WJGM, Rosenbaum R, van de Meent D, Vijver MG. The clearwater consensus: The estimation of metal hazard in fresh water. International Journal of Life Cycle Assessment 2010; 15:143–147.

Hope BK, **Wickwire T**, and Johnson MS. The need for increased acceptance and use of spatially explicit wildlife exposure models. Integrated Environmental Assessment and Management 2011; 7(2): 156–157.

McArdle ME, **Kane Driscoll SB**, **Booth PN**. An ecological risk-based cleanup strategy for contaminated sediments in a freshwater brook. International Journal of Soil Sediment and Water 2010; 3(2):1–24.

Moore DRJ, Warren-Hicks WJ, Qian S, **Fairbrother A**, Aldenberg T, Barry T, Luttik R, Ratte H-T. Uncertainty analysis using classical and Bayesian hierarchical models. In: Application of Uncertainty Analysis to Ecological Risks of Pesticides. Hart A, Farrar D, Urban D, Fischer D, LaPoint T, Romijn K, Ferson S (eds), SETAC Press, Pensacola, FL, in press.

O'Reilly KT, **Thorsen W**. Impact of crude oil weathering on the calculated effective solubility of aromatic compounds: Evaluation of soils from Ecuadorian oil fields. Soil and Sediment Contamination 2010; 19:391–404.

O'Reilly KT, **Pietari J**, **Boehm P**. A review of PAHs: Polycyclic aromatic hydrocarbons in stormwater and urban sediments. Stormwater 2010; 11(6):10–21.

Page DS, **Boehm PD**, Neff JM. Comment on "Unlike PAHs from Exxon Valdez Crude Oil, PAHs from Gulf of Alaska Coals are not Readily Bioavailable." Environmental Science and Technolology 2010; 44.

Palmquist K, **Fairbrother A**, **Salatas J**, Guiney P. Environmental fate of pyrethroids in urban and suburban stream sediments and the appropriateness of Hyalella azteca model in determining ecological risk. Integrated Environmental Assessment and Management DOI: 10.1002/ieam.162. (in press).

Saba T, **Boehm PD**. Congener-based analysis of the weathering of PCB Aroclor® 1242 in paper mill sludge. Chemosphere 2011; 82:1321–1328.

Shields WJ, Chan WR. Fugitive dust: Methods for estimating emission of contaminated wind-blown particles. pp. 22–29. In: Environmental Forensics: Proceedings of the 2009 INEF Annual Conference. Morrison R, O'Sullivan R (eds), Royal Society of Chemistry, London, 2010.

Wickwire T, Johnson MS, Hope BK, and Greenberg, MS. Spatially explicit ecological exposure models: A rationale for and path toward their increased acceptance and use. Integrated Environmental Assessment and Management 2011; 7(2):158–168.

Wickwire T, **Menzie CA**. The causal analysis framework: Refining approaches and expanding multidisciplinary applications. Human and Ecological Risk Assessment 2010; 16(1).

Ziccardi L, **Salatas J**. The ecological effects of nanomaterials: A risk assessment perspective. ABA Science and Technology Newsletter 2010; 7(1).

Book Chapters

McLaughlin MJ, Lofts S, Warne M St. J, Amorim MJB, **Fairbrother A**, Lanno, R, Hendershot W, Schlekat CE, Ma Y, Paton GI. 2010. Derivation of ecologically-based soil standards for trace elements. pp.6–84. In: Soil quality standards for trace elements. Merrington G and Schoeters I. (eds). CRC Press, Boca Raton, FL.

Moore DRJ, Warren-Hicks WJ, Qian S, **Fairbrother A**, Aldenberg T, Barry T, Luttik R, Ratte H-T. Uncertainty analysis using classical and Bayesian hierarchical models. In: Application of Uncertainty Analysis to Ecological Risks of Pesticides. Warren-Hicks WJ, Hart A. (eds). SETAC Press, Pensacola, FL, USA. 2010.

Conferences & Presentations

Dioxin Conference, September 12–17, 2010, San Antonio, TX

Saba T, **Boehm PD**. Congener-based analysis of the weathering of PCBs in paper mill sludge.

Shields WJ, Tondeur Y, Hart J, **Edwards MR**, **Benton LD**, **Pietari J**. PCDD/F fingerprinting with 17 congeners – What about the other 193?

Society of Environmental Toxicology and Chemistry (SETAC) Annual Conference, November 7–11, 2010, Portland, OR

Platform Presentations

BenKinney MT, **Brown JS**, **Mudge SM**. Evaluation of the Ecological Impact of Surface Application of Corexit EC9500A Dispersant on Oil from the MC252 Deepwater Horizon Incident

Boehm PD, Page DS, Neff JM, **Brown JS**. Are Sea Otters Still Exposed to Oil Remnants 21 Years after the Exxon Valdez Oil Spill?

Booth PN, Montgomery RH. Conceptual Framework and Technical Approach for Evaluating Risks to Critical Natural Habitat under Lending Programs of Multilateral Banks

Fairbrother A, **Edwards M**. Contaminant Analysis of Fish in the Upper Columbia River, Washington

Fairbrother A, **Menzie CA**. Integrated Exposure Analysis for Human Health and Ecological Risks at Contaminated Sites

Gard NW. Summary of a Special Session on Global Stressors held at the 20th Meeting of SETAC Europe, Seville, Spain

Menzie CA. Perspectives on the Application of Ecological Services: An Introduction to the Session

Mudge SM, **Brown JS**, **BenKinney MT**. Tracking the Dispersant

Neff JM, Page DS, **Boehm PD**, **Brown JS**. Are Harlequin Ducks Still Exposed to Oil Remnants 21 Years After the Exxon Valdez Oil Spill?

O'Reilly K, Brown JS, **Pietari J**, **Boehm PD**. Identifying the Chemical Footprint of Resource Damages Caused by the Release of Petroleum from Fuel Terminals

O'Reilly K, **Pietari J**, **Boehm PD**. PAHs in Urban Sediments: Forensic Approaches for Assessing the Relative Contribution of Atmospheric Deposition and Parking Lot Sealants

Page DS, **Boehm PD**, **Brown JS**, Neff JM. Status of Remaining Oil 21 Years After the Exxon Valdez Oil Spill in Prince William Sound, Alaska

Palmquist K, **Fairbrother A**, **Salatas JH**. Environmental Fate of Pyrethroids in Urban Stream Sediments and the Appropriateness of Hyalella azteca Model in Determining Ecological Risk

Shields WJ, **Pietari J**. Historic Reconstruction of Contaminant Releases at Military Shipyards during World War II

Staveley JP, Sellers K, Hassinger C, Endris R. Environmental Assessment of the Antibiotic Florfenicol for Use in a Variety of Aquaculture Systems

Staveley JP, Sellers K, Hassinger C, Endris R. Environmental Assessment of the Use of SLICE® (Emamectin Benzoate) in Saltwater Aquaculture

Panel Presentation

Boehm PD. Oil Spill in the Gulf of Mexico: The Ixtoc 1 Blowout in the Bay of Campeche

Poster Presentations

Booth PN, **Law S**, **Ma J**. Ecosystem Service Considerations for Corporate Land Management: Emerging Ecosystem Service Tools and a Case Study of Comparative Tool Application

Booth PN, **Salatas JH**. The Great Lakes Legacy Act, Great Lakes Restoration Initiative, and NRDA: The Potential for Synergy

Brown JS, **Mudge SM**. PAH Depletion Ratios, Document the Rapid Weathering and Attenuation of PAHs in Oil Samples Collected after the Deepwater Horizon Incident

Edwards M, **Fairbrother A**. Surface Water Quality in the Upper Columbia River, Washington

Gard NW, **Menzie CA**, **Fairbrother A**. Stressor Analysis Approaches for Endangered Species Assessments

Hope BK, **Wickwire WT**. An Overview of Available Spatially Explicit Exposure Models

Johns M, Beckmann D. Deepwater Dispersant Use and Evaluation of Subsea Monitoring and Analytical Laboratory Results for the MC252 Spill

Johnson MS, **Wickwire WT**. Improving Wildlife Risk Predictions Through the Integration of Spatial and Habitat Effects: An Application of the Spatially-explicit Exposure Model

Kierski MW, **Morrison AM**, **Kane-Driscoll S**, **Menzie CA**. Use of Receiver Operating Characteristic Curve Analysis to Estimate Ecological Risk Zones as Part of an Ecological Risk Assessment

Law S, **Fairbrother A**. When Worlds Collide: Reconciling the Often Opposing Agendas of Economic Growth and Wildlife Sustainability

Wickwire WT. Spatially Explicit Wildlife Exposure Models: A Pathway to Wider Acceptance and Application – Overview of Poster Series

Sixth International Conference on Remediation of Contaminated Sediments, February 7–10, 2011, New Orleans, LA

Babcock D, Nolan J, Roth P, Kuhr K, **Henry B**, Matthews D. Deployment of Soluble Nitrate to Minimize Methylmercury Release from Anoxic Lake Sediment

Boehm PD, **Brown JS**, **Cook LL**, **O'Reilly K**, **Pietari J**. 2011. Determination of the Petroleum and PAH Footprint in Sediments from Fuel Terminal Releases

Glaser D, **Henry B**, Kelsall N, Murphy M, Brown S. Preliminary Evaluation of Mercury Bioavailability in Berry's Creek, NJ

Henry B, Gilmour C, Reidel G, Ghosh U, Kwon S, **Menzie C**, Brown S. Evaluation of Sorbent Amendments to Mitigate Methylmercury Production and Bioaccumulation in Berry's Creek, New Jersey

Henry B, Murphy M, Glaser D, Todorova S, Driscoll C, Matthews D, Effler S. Decrease in Mercury Concentration in Onondaga Lake Biota in Recent Years

Menzie C, **Kierski M**, **Saba T**, Meyer S, Kovatch E, Kahler J, Fox R, Kern J. Multisite Ambient Investigation for MGPs on the Chicago River

Pietari J, **O'Reilly K**, **Boehm P**. 2011. Environmental Forensics for PAH Source Management: Pavement Sealants and Sediments

Pietari J, **O'Reilly K**. 2011. Remediation and Restoration of Contaminated Sediments: Who Is Going to Pay?

Saba T, **Boehm PD**. Quantitative PCB Congener and Homologue Profile Comparisons

Menzie CA. 2010. Health and Environmental Risks of CO2 Sequestration in Geological formations. Special Lecture at Lehigh University, March 4, 2010.

Menzie CA, Luthy R. 2011. Contaminated Sediments: New tools and approaches for *in-situ* remediation - Session III. Sponsored by National Institute of Environmental Health Sciences, Superfund Research Program. January 19, 2011. Presentation recorded and available through NIEHS, at http://www.clu-in.org/conf/tio/sediments3_011911/.

Menzie C, **Cantor R**, **Boehm P**, Bailey JR. An Approach to Business Vulnerability and Risk Assessments Related to Climate Change. Paper presented at the Society of Petroleum Engineers International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, April 12–14, 2010, Rio de Janeiro, Brazil.

O'Reilly KT, **Menzie CA**. 2010. Endangered Species: Chemicals, Places, and Climate Change. 39th ABA Environmental Law Conference, March 18–20, 2010. Salt Lake City, UT.

Patterson D. 2010. Three oral presentations:

1) Comprehensive fingerprinting of chemical mixtures for environmental and biological forensics
2) Use of GCxGC-HRMS and comprehensive GCxGC-TOFMS for assessing human exposure to environmental toxicants and screening for new and emerging chemicals
3) Patterns of multicomponent persistent and non-persistent chemicals in human biomonitoring studies.

Presented at International Chemical Congress of the Pacific Basin Societies (Pacifichem 2010), December 15–20, 2010, Honolulu, HI.

Exponent Webinars
(available at www.exponent.com/webinars)

Mudge S, **Gard N**. Implementing the Environmental Liability Directive. February 3, 2010.

Menzie CA, **Booth P**, **Saba T**. PCB Update: What's new, what you need to know, and why. March 31, 2010.

Boehm P, **Anderson E**, **Kane Driscoll S**. PAHs: What you need to know and why. May 19, 2010.

Shields W, **Karch N**, **Patterson D**. Dioxin updates: What's new, what you need to know, and why. June 30, 2010.

Haussmann G, **Menzie C**, **Murphy B**. Chemical plant accidents and toxic torts. November 19, 2010.

Brugger G, **Mohsen F**, **Yost L**. Solvents: Hot topics in risk and remediation. December 14, 2010.

Staveley J, **Robrock K**. Pharmaceuticals and personal care products in the environment: Technical and regulatory issues. March 2, 2011.

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