Environmental Toxicology and Risk Assessment

Modeling and Risk Assessment

SIXTH VOLUME

F. James Dwyer, Thomas R. Doane, and Mark L. Hinman, editors

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F. James Dwyer, Thomas R. Doane, and Mark L. Hinman, Editors

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Foreword

The Sixth Symposium on Environmental Toxicology and Risk Assessment was presented in Orlando, FL on 15–18 April, 1996. ASTM Committee E47 on Biological Effects and Environmental Fate sponsored the symposium, which was the 23rd symposium sponsored by the committee. The focus of the Sixth Symposium on Environmental Toxicology was on the use of modeling in developing risk assessments for a variety of situations, including human-health assessments, site-specific assessments, and ecosystem-level assessments. F. James Dwyer, Midwest Science Center, National Biological Service, chaired the symposium. Co-chairs were Thomas R. Doane, Battelle-San Antonio Operations, and Mark L. Hinman, Exxon Biomedical Sciences, Inc. Each of these men served as editors of the resulting publication.

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Toxicology–Aquatic, Plant, Sediment, and Soil

Overview

ASTM Committee E-47 on Biological Effects and Environmental Fate held its Sixth Symposium on Environmental Toxicology and Risk Assessment in Orlando, FL during April 15-18, 1996. This symposium was the 23rd associated with Committee E-47 and this is the 25th Special Technical Publication (STP) originating from the symposiums. (See Appendix I for a complete list of STPs.) The focus of the symposium was the use of modeling in developing risk assessments for a variety of environmental situations. The symposium was a success in spite of travel restrictions which have become a recurring problem for many of our participants. The symposium opened with a plenary session, and over the course of three days had 10 platform sessions, a poster session, a hosted luncheon with a guest speaker and a workshop. This STP reflects the symposium in that the first section entitled "Modeling Perspectives" has six papers which relate to the use of modeling in risk assessments. Moreover, as the reader of this STP will notice, various aspects of modeling are included in the sections "Ecological Risk Assessment" and "Human Health Risk Assessment". In fact, many papers in these three sections could easily have been grouped differently.

The plenary session was titled "Planning the Perfect Risk Assessment" and focused on several aspects that risk managers should consider when conducting a risk assessment. The speakers discussed four primary topics: 1) when is risk assessment the right tool?; 2) communication of risk assessment; 3) model selection and problem analysis; and 4) data quality and uncertainty.

The issue of risk communication was a topic that came up many times during the three days of the symposium; from the dais, during subcommittee meetings, and during informal discussions. The interest in, and the recognition of the need for standardization in risk communication, resulted in the formation of a new subcommittee under E-47: E47.14 on "Balancing and Communicating Environmental Risk Management Decisions". This new subcommittee had their first formal gathering seven months later during the fall E-47 Committee meeting prior to the 1996 Society of Environmental Toxicology and Chemistry annual symposium in Washington, DC. E47.14 promises to be an active subcommittee.

A first for E-47 at this symposium was the workshop, "ASTM Standards for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Invertebrates". This introductory workshop was attended by 40 individuals and was designed for individuals with minimal experience in conducting sediment toxicity or bioaccumulation tests. The objectives of the course were to: (1) describe procedures for conducting whole-sediment toxicity and bioaccumulation tests with freshwater, estuarine, and marine invertebrates; (2) provide an overview of a proposed standard guide for conducting sediment toxicity tests with luminescent bacteria; and (3) discuss approaches for data interpretation. The workshop was coordinated by Christopher G. Ingersoll, Ph.D. (Midwest Science Center, USGS-BRD, Columbia, MO) and instructors included: Michael D. Johns, Ph.D. (EVS Environmental Consultants, Seattle, WA), Nile E. Kemble (Midwest Science Center, USGS-BRD, Columbia, MO), Donald J. Reish, Ph.D. (California State University, Long Beach, CA), and Philippe E. Ross, Ph.D. (The Citadel, Charleston, SC).

The luncheon, held on Wednesday, was an excellent opportunity to hear about an issue of regional significance in Florida - the Everglades. The speaker, Wiley M. Kitchens, Ph.D. from the USGS, Florida Carribean Science Center, Gainesville, FL presented a slide tour/overview of the Everglades. His presentation, "The Everglades: The Ecosystem and Its Restoration Issues" with both scenic and technical slides, gave an excellent overview of how the Everglades degraded to its current status and the changes that are being implemented to improve its condition. In our field, it is a rare but wonderful experience to have a person not only speak about the problems but to also discuss the improvements and successes!

As evidenced by the plenary session, the number of platform sessions and posters, and the new subcommittee activity, risk assessment has become a growing focus of Committee E-47. The same is true of this STP. Three of the five sections - Modeling Perspectives, Ecological Risk Assessment, and Human Health Risk Assessment - focus on the diverse topic of risk assessment. Papers have discussions covering a wide spectrum of risk assessment topics including the intricacies of various models, the application of models in conducting risk assessments, and procedures for conducting risk assessments. Topics include both environmental and human health risk assessment in all three media - soil, air, and water.

While risk assessment may be the primary topic of this STP, two other major areas, Biomarkers and Toxicology, were well represented at the symposium and within the pages of this STP. The study of biomarkers is still a growing field and as such was a well-attended session at the symposium. The STP has five papers from the symposium which represent the state of the art in technique and application of biomarkers. The Toxicology section, "Toxicology - Aquatic, Plant, Sediment, and Soil", as its title shows, contains several papers describing new or modified procedures which will ultimately provide information useful to the ASTM standardization process. Other papers focus on the utility of data generated using different approaches. This information will be of use as standards and guides evolve.

We have many individuals to acknowledge for both the symposium and the STP. We would like to thank the session chairs who recruited speakers and organized sessions which provided the basis for the papers that are included in this STP: Plenary, Gregory R. Biddinger, Ph.D. (Exxon Company USA, Houston, TX); Sediment Toxicology, Nile E. Kemble (USGS-BRD, Midwest Science Center, Columbia, MO); Risk-Based Strategies and Models, Tim LeGore (Westinghouse Hanford Company, Richland, WA); Phototoxicology and Plant Toxicology, Bruce M. Greenberg, Ph.D. (University of Waterloo, Waterloo, ON); Community Dynamics and Ecotoxicology from Individual-Based Modeling Perspectives, Thomas G. Hallam, Ph.D. (University of Tennessee, Knoxville, TN) and S.A.L.M. Kooijam, Ph.D. (Vrige University, Amsterdam); Exposure Assessment, Joan G. Tell, Ph.D. and Annette Guiseppi-Elie, Ph.D. (Exxon Biomedical Sciences, Inc., East Millstone, NJ); Biomarkers, Marsha C. Black, Ph.D. (University of Georgia, Athens, GA) and Diane S. Henshel, Ph.D. (Indiana University, Bloomington, IN); Environmental Monitoring and Modeling, Jerome M. Diamond, Ph.D. (Tetra Tech, Inc., Owings Mills, MD); Policy and Perspectives in Ecological Risk Assessment, Charles A. Pittinger, Ph.D. (Procter & Gamble Co., Cincinnati, OH) and Joseph W. Gorsuch (Eastman Kodak Company, Rochester, NY); Aquatic Toxicology, Timothy J. Canfield (USGS-BRD, Midwest Science Center, Columbia, MO); Human Health Risk Assessment, Lenora P. Midgley, Ph.D. (R&R Technologies, Inc., Salt Lake City, UT) and the poster session Brian A. Wade, (ALA Environmental, Inc, Gainesville, FL) and Gail

symposia may focus on specific or unique environmental issues, the urgency and importance of risk assessment, and all the various attributes of the assessment, will remain an important topic for some time to come. Some groups have questioned the role of ASTM in developing standard guides for professional judgment and evaluation within risk assessment. The ASTM consensus building process allows the opportunity for input by every member on every procedure. Ultimately, the development of guides and standards provides a basis for individuals to make a judgment. Without consistency in techniques, judgments and evaluations are without foundation. We believe this STP, and the symposium upon which it is based, are key parts of that consensus process. Techniques and procedures will be added to, modified, and qualified based on information from this symposium and the consensus-building process will continue.

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Modeling Perspectives

Thomas P. Burns[1], Charles T. Hadden[1], Barney W. Cornaby[1], and Stephen V. Mitz[1]

A FOOD WEB MODEL OF MERCURY TRANSFER FROM STREAM SEDIMENT TO PREDATORS OF FISH FOR ECOLOGICAL RISK BASED CLEAN-UP GOALS

REFERENCE: Burns, T. P., Hadden, C. T., Cornaby, B. W., and Mitz, S. V., **"A Food Web Model of Mercury Transfer from Stream Sediment to Predators of Fish for Ecological Risk Based Clean-Up Goals,"** Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment (Sixth Volume), ASTM STP 1317, F. James Dwyer, Thomas R. Doane, and Mark L. Hinman, Eds., American Society for Testing and Materials, 1997.

ABSTRACT: A linear steady state model of the food web linking sediment to piscivorous predators was used to derive ecological risk based clean-up concentrations for mercury in sediment of East Fork Poplar Creek (EFPC), Oak Ridge, TN. The model partitions aquatic invertebrates into two classes based on the primary source of exposure to mercury in sediment, and the prey-fish community into three classes based on differences in their diets and feeding habits. Biotransfer factors for the links between sediment and sediment-dwelling invertebrates, water and aquatic biota and fish, and prey and predators are published values. The model uses site specific data on the fraction of methylmercury in sediment, the relative abundance of prey fish, and the predicted flux of mercury from sediment. Monte Carlo analysis quantifies the uncertainty in the risk to top predators of fish. At 96 mg/kg mercury in sediment, less than 20% of the exposures exceed dietary limits for endpoint receptors. The fraction of methylmercury in sediment, the three biotransfer factors for methylmercury, and diet are sensitive parameters.

KEYWORDS: Aquatic, bioaccumulation, bioconcentration, food web, methylmercury, remedial goal options, sediment, sensitivity

Remediation of contaminated sites often requires establishing remedial goal options (RGOs) based on ecological risk. RGOs are concentrations of substances in soil, sediment, or other source media that serve as potential target concentrations for clean-up of those media. RGOs can be based on applicable or relevant and appropriate requirements as established by law, the limitations of remedial technologies, funding constraints, background levels of contamination, policy considerations, or risk. Risk based RGOs are the maximum concentrations predicted to provide an acceptable level of protection for both humans and nonhuman or 'ecological' receptors.

Ecological risk based RGOs are often difficult to establish. They depend critically on the conceptual model of the site, including what wildlife receptors are potentially most at risk and what potential exposure pathways link those receptors to the contaminated source medium. Unlike the situation with human-health risk, there is little regulatory guidance on how to estimate RGOs based on risk to ecological

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receptors, such as fixed exposure parameters, scenarios, and receptor groups (EPA 1989). Rather, a completely site specific model of exposure is usually necessary to derive ecological risk based RGOs.

Models are required for ecological risk based clean-up levels whenever the contaminant concentration to which the receptor is exposed is not identical to the concentration in the source medium. This commonly occurs for three reasons. The first is that many biota are exposed to different concentrations of a contaminant in different places within the same ecosystem. In this case, the exposure concentration can not be directly predicted from any particular concentration in the source medium. A second common situation is when biota are exposed to a contaminant with more than one source medium. The third is when there are intervening media or processes that increase or decrease the contaminant concentration as the contaminant moves from source medium to the receptor.

Deriving RGOs for contaminants in freshwater sediment is likely to involve more than one of these complications. If endpoint receptors are wide ranging organisms, such as fish or their predators, sediment RGOs will require modeling the exposure to biota that are exposed to different concentrations of the contaminant in different locations, including background concentrations (MacIntosh et al. 1994). In these cases, a model of the receptor's movement among sites with varying contaminant concentrations may be required. Another alternative is to assume uniform exposure over all contaminated areas and clean up to a single concentration everywhere. For most receptors that do not live in direct contact with the sediment, models of contaminant transport, transformation, and dilution or magnification will be required to derive ecological risk based RGOs. Models of varying complexity have been developed to estimate the exposure of aquatic biota to contaminants in sediment (Thomann and Connolly 1984, Thomann 1989, Clark et al. 1990, Gobas 1993). In many cases, there will be other sources (e.g., floodplain soil, surface water) that impede using direct measurement of contaminant concentrations in the exposure medium to derive risk based clean-up levels for the source medium. In these cases, modeling is required to predict the contributions from the source medium of interest.

Here, we describe a food-web model that was used to derive ecological risk based RGOs for mercury in the sediments of a perennial stream with two source media, surface water and sediment, and varying concentrations of mercury in stream sediments. The model estimates the exposure of wide ranging piscivorous predators to mercury in sediment indirectly via the food web, assuming that the only source of mercury to surface water is the sediment. The food web model includes two groups of invertebrate prey with different degrees of exposures to mercury in sediment and three types of forage fish that eat these prey groups in different proportions. These simple partitions of the two trophic groups allow efficient use of recent information about mercury dynamics and bioaccumulation in aquatic food webs, and thus may be useful to other modelers assessing risk or deriving RGOs for mercury. The approach to modeling the aquatic food web may also be useful at other sites with contaminated sediment, especially those with contaminants that bioaccumulate (e.g., organics), because the simple food web may be adapted to other sites using site specific data on abundance and diet.

SITE HISTORY

East Fork Poplar Creek (EFPC) is a perennial stream flowing through the City of Oak Ridge, TN (Fig. 1). EFPC and its floodplain are contaminated with thousands of kilograms of mercury. Mercury in EFPC originated primarily from the U.S. Department of Energy (DOE) Y-12 Plant, which began separation of lithium isotopes for the nuclear weapons program in 1953. In the decade that followed, millions of kilograms of elemental

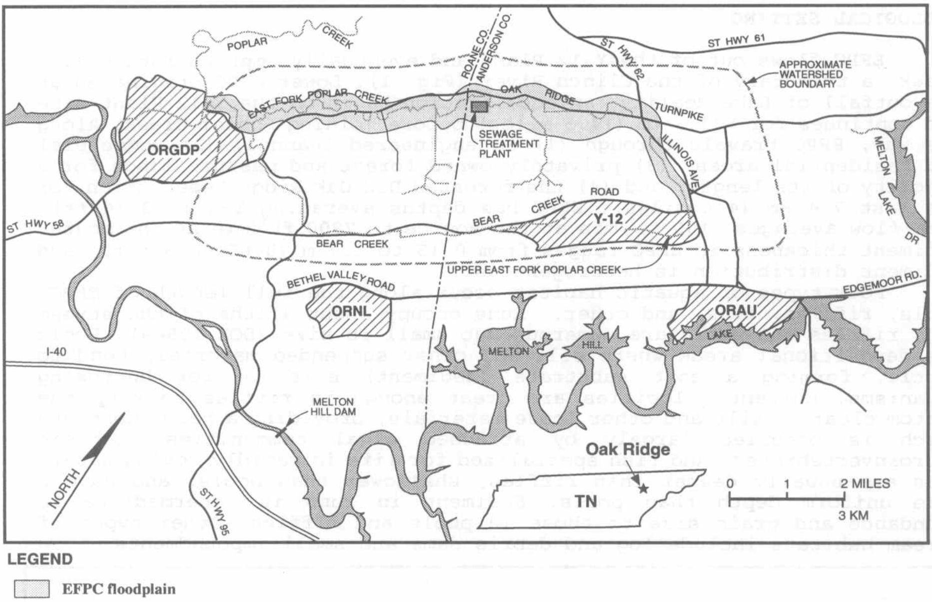

FIG. 1. Map of EFPC and surroundings

mercury were used in the lithium-separation process at Y-12. Between 1953 and 1985, an estimated 108,000 to 212,000 kg (239,000 to 490,000 lb) of mercury as metal were released into EFPC. Mercury continues to be released into EFPC from sewer pipes, sumps and other unlocated sources in the Y-12 Plant, although at much reduced rates (Turner et al. 1985, Norris 1993). As a result, aquatic and terrestrial wildlife are exposed directly or indirectly to mercury in sediment, surface water or both.

In 1989, the Oak Ridge Reservation, which includes EFPC, was placed on the National Priorities List and designated as a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site. The design of remedial alternatives and evaluation of their cost and effectiveness mandated under CERCLA requires RGOs to evaluate remedial alternatives.

Ecological risk based RGOs were derived for mercury in EFPC sediments using modeled exposures for aquatic biota and their terrestrial predators. Three models were used to derive RGOs for five classes of non-human biota under three different sets of exposure assumptions (DOE 1995). The results of the modeling provided a range of ecological risk based RGOs for EFPC sediment, from extremely conservative RGOs (low concentrations) based on maximum exposures to more realistic values based on site specific data and published literature data resulting in lower exposures and higher RGOs. The application of these models to the CERCLA process for lower EFPC is described elsewhere (Hadden et al. unpublished manuscript). Here we describe and analyze the food-web model used to derive RGOs for top predators of fish in EFPC. A probabilistic model using Latin Hypercube sampling from specified distributions of parameter values is substituted for the three discrete (point estimate) exposure scenarios originally evaluated.

ECOLOGICAL SETTING

EFPC flows out of the Y-12 Plant and eventually empties into Poplar Creek, a tributary of the Clinch River (Fig. 1). Lower EFPC originates at the outfall of Lake Reality, an equalization basin on the Y-12 Plant site and continues for >23.3 km (14.5 miles) before joining Poplar Creek. Along its way, EFPC travels through (1) an engineered channel, (2) commercial and residential areas, (3) privately owned forest and pasture lands for a majority of its length, and (4) the forested DOE Oak Ridge Reservation for the last 7.4 km (4.6 miles). EFPC has depths averaging 1-3 m (3-10 ft). Base flow averages 1100 ft^3/min at the source to 7800 ft^3/min at the mouth. Sediment thickness in EFPC ranges from 0.15 to 1.7 m (0.05 to 5.5 ft) and sediment distribution is heterogeneous.

Four types of aquatic habitat occur along the full length of EFPC: pools, riffles, runs, and other. Runs occupy about 3/4ths of the stream bed; riffles and pools are numerous but small in size (DOE 1994a). Pools are depositional areas where silt and other suspended materials tend to settle, forming a soft substrate (sediment) suitable for burrowing organisms. Current velocities are great enough in riffles to keep the bottom clear of silt and other loose materials, providing a hard substrate which is occupied largely by attached algal communities, benthic macroinvertebrates, and fish specialized for life in rapidly moving water. Runs are usually deeper than riffles, shallower than pools, and have a more uniform depth than pools. Sediment in runs is intermediate in abundance and grain size to those in pools and riffles. Other types of stream habitats include log and debris dams and small impoundments.

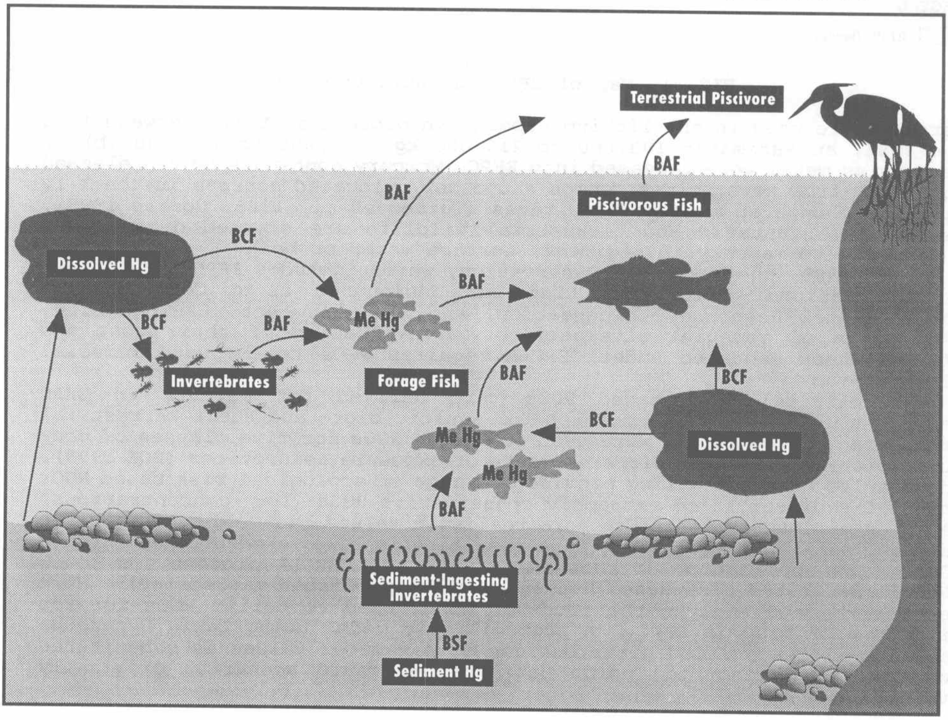

FIG. 2. Flows of mercury in EFPC aquatic ecosystem for sediment RGOs based on biological transfers