United States Environmental Protection Agency
Environmental Research Laboratory
Athens GA 30613
Research and Development
EPA/600/M-88/011 Aug. 1988

EPA ENVIRONMENTAL RESEARCH BRIEF

EPA's Ecological Risk Assessment Research Program October 1985 - March 1988

Harvey W. Holm, Program Manager

By Congressional mandate, the U.S. Environmental Protection Agency must determine whether individual chemicals, either new or existing, can be manufactured and sold in the United States. The evaluation process for each chemical includes an ecological risk assessment.

The number of chemicals requiring review is large. In 1986, for example, the Agency's Office of Toxic Substances (OTS) had more than 60,000 existing chemicals on inventory and also processed more than 1500 new chemicals (Premanufacture Notices). The challenge for OTS is to provide realistic, consistent evaluations within short time frames when only a limited data set is provided. Often, OTS must make screening level decisions when only a chemical's structure, its proposed use pattern, and two to three bioassay results (collected under only one set of laboratory conditions) are available. It is very unusual for OTS to have site-specific information on fate, exposure, or effects for the premanufacture notice process.

EPA's Office of Pesticide Programs (OPP) also has a gigantic problem. More than 50,000 existing pesticide products must be evaluated, with new products being developed each year. Although OPP can require submission of significant amounts of fate and effects information, it still faces the challenge of extrapolating results from one ecosystem to another and from a limited number of test species and exposure scenarios to a myriad of natural populations.

The Office of Pesticides and Toxic Substances (OPTS) recognizes ecological risk assessment as a synthesis of toxicological hazard and environmental exposure. Toxicological hazard is the intrinsic quality of a chemical to cause adverse effects, such as death (characterized by an LC_{50}) or a chronic effect (such as reproductive failure) when exposure occurs. Environmental exposure is a function of the amount of toxic chemical available to components of ecosystems and the distribution and dynamics of organisms within these ecosystem components. An ecological risk assessment, then, involves systematically combining results from exposure and hazard assessment.

Numerous techniques have been suggested and sometimes used by OPTS for ecological risk assessment. These include fault tree analysis, safety factor evaluation, ecosystem uncertainty analysis, and predictive ecosystem modeling.

The most commonly used technique, however, is the quotient method. This methodology compares a toxicological benchmark (such as LC_{50}, EC_{50}, etc.) to an anticipated level of exposure. The closer the exposure and effects numbers approach each other, the higher the risk value. This technique is simple and straightforward. Its disadvantages are that it does not take into account dose-response relationships, that it provides no basis for predicting population or system-level responses, that it does not account for ranges in hazard and exposure estimates, and that it cannot address indirect effects of chemicals.

To improve capabilities for assessing and predicting risk to ecosystems, the Office of Research and Development (ORD) initiated a comprehensive research program in consultation with OPTS. The research, which began in October 1986, was undertaken by the Office of Environmental Processes and Effects Research's (OEPER's) Environmental Research Laboratories in Athens, GA, Corvallis, OR, Duluth, MN, and Gulf Breeze, FL. The Athens Laboratory was designated as the lead laboratory.

OPTS and ORD established several goals for this research:

- Identify critical ecological components for assessment.
- Develop techniques for extrapolating laboratory and limited field data to other systems.
- Provide systematic procedures to permit consistent ecological evaluations among analysts.
- Provide insights into "so what" questions (e.g., "so what" if primary productivity in lakes is decreased by 25%).

OEPER's approach to this problem is primarily one of developing system-independent mathematical models and protocols for exposure and hazard assessment and of embedding them in a computer-based "Decision Support System" that provides convenient access to these models, protocols, and databases essential for completing ecological risk assessments. The models and protocols generated in this research have four characteristics in common.

1. They are based on fundamental understanding of primary ecotoxicological processes and, thus, may require specific research to achieve the prerequisite level of scientific knowledge for routine application.
2. They are formulated in "system-independent" terms so that reliable extrapolations among systems are possible; that is, the only use made of observed datasets that are in the output domain of the models is for validation studies.
3. They result in the generation of mathematical formulations and computational algorithms that will be encoded in computer programs, thus providing a formal statement of methods that is objective, reproducible, readily available, and accessible to external peer evaluation and public appraisal.
4. They are linked to specific databases assembled (in each project as appropriate) to provide the maximum feasible geographic coverage; the databases will contain virtually all the collateral (i.e., not specific to the regulatory concern under analysis) data needed to apply the models.

To achieve its goal, OEPER's Ecological Risk Assessment Research Program relies heavily on results from EPA's base chemical exposure and hazard assessment research and development efforts. The major emphasis in the current program is to integrate results from these two areas to provide the scientific basis for assessing ecological risks. The present state of the art of research in chemical exposure and hazard evaluation has not adequately covered all subject areas needed to provide tools for ecological risk assessment. Existing research results, ongoing research in the areas of chemical exposure and hazard evaluation, and complementary new research conducted in this program will provide a foundation for developing a scientifically sound ecological risk assessment capability for the Agency.

Three elements of any risk assessment (exposure analysis, hazard analysis, and the integration of the two into a risk analysis) are addressed in research involving six levels of integration of individual projects. Aside from levels A and B, each succeeding level of the project represents a higher level of integration and, therefore, may derive its mechanistic knowledge and summary descriptive models from results at lower levels. For example, projects at the level of population and ecosystems (level E) may use some of the results of research on toxicological impacts on individual organisms (research level D). The kinds of research projects, their level of integration ("A" through "F"), some correlative toxicological nomenclature, and results to date are provided below.

(A) Decision Support Systems—computer software and databases that allow an analyst to assemble and deploy the specific array of analytical tools needed for an ecological risk assessment. These "integration" projects assemble the executive software that allows the user to interact with the models, access databases, and provide service functions for all the models eventually in the system.

(No published reports available)

(B) Exposure Analysis—release, transport, and transformation of xenobiotic chemicals in the physical environment. This research plan does not initiate significant new research in the transport and transformation of pollutants in ecosystems, which is a well-developed field in its own right. In the Ecological Risk Assessment Research Program, we intend to adapt existing models to the needs of the dependent ecological models, and to sponsor such remedial work as may be necessary to bring all the exposure models in the project to a commensurate state of sophistication.

Ambrose, R. B., T. A. Wool, J. P. Connolly, and R. W. Schanz. 1987. WASP4, A Hydrodynamic and Water Quality Model—Model Theory, User's Manual, and Programmer's Guide. U.S. Environmental Protection Agency, Athens, GA. EPA/600/3-87/039.

Demonstration of the Terrestrial Environmental Exposure Assessment Model (TEEAM), Office of Pesticides and Toxic Substances, Washington, DC, December 1987.

Demonstration of Pesticide Leaching Model and Associated Soils/Climate Data Bases, Office of Pesticides and Toxic Substances, Washington, DC, March 1988.

(C) Toxicokinetics—exchange of xenobiotics between individual organisms and their environment, and the transport and transformation of xenobiotic chemicals within the organism. These projects encompass the area of mechanisms and processes that translate an initial exposure into a realized tissue dose at a target organ. In human studies, it would include some aspects of both hazard identification and dose-response assessment; wildlife biologists regard the

behavioral response to initial contact with pollutants as an aspect of exposure assessment.

Barber, M. C., L. A. Suarez, and R. R. Lassiter. 1987. FGETS (Food and Gill Exchange of Toxic Substances): A Simulation Model for Predicting Bioaccumulation of Nonpolar Organic Pollutants by Fish. U.S. Environmental Protection Agency, Athens, GA. EPA/600/3-87/038.

Barber, M. C., L. A. Suarez, and R. R. Lassiter. 1988. Bioconcentration of nonpolar organic pollutants by fish. Env. Tox. Chem. (accepted).

Barber, M. C., L. A. Suarez, and R. R. Lassiter. 1988. Kinetic exchange of nonpolar organic pollutants by fish. Env. Tox. Chem. (accepted).

Boersma, L., T. Lindstrom, C. McFarlane, and E. L. McCoy. 1988. Uptake of organic chemicals by plants: A theoretical model. Soil Sci. (accepted).

Boersma, L., T. Lindstrom, C. McFarlane, and E. L. McCoy. 1988. Model of coupled transport of water and solutes in plants. Oregon State University, Corvallis, OR. Special Publication 818.

Boersma, L., C. McFarlane, and T. Lindstrom. 1987. Uptake and transport of chemicals by plant. Three leaf model. (Version 2.1) User Guide. Oregon State University, Corvallis, OR. Special Publication 819.

Fletcher, J. S., A. Groeger, and C. McFarlane. Metabolism of 2-chlorobiphenol by suspension cultures of Paul's Scarlet Rose. Soc. for Envir. Tox. and Chem. (submitted).

Fletcher, J. S., A. Groeger, J. McCrady, and C. McFarlane. 1987. Polychlorobiphenyl (PCB) uptake by plant cells. Biotechnology Letters 9(11):817-820.

Groeger, A. and J. S. Fletcher. Influence of increasing chlorine content on the accumulation and metabolism of polychlorobiphenyls (PCBs) by plant cultures. Plant Cell Reports (submitted).

Heitmuller, P. T. and J. R. Clark. Bioaccumulation of 1,2,4-trichlorobenzene from food and water sources by spot (*Leiostomus xanthurus*). Aquatic toxicology and hazard assessment. American Society for Testing and Materials, Philadephia, PA (In Press).

Lindstrom, F. T., L. Boersma, and C. McFarlane. 1987. A steady state fluid transport model in plants. *In*: James, L. G. and J. Marshall (eds.), Irrigation Systems for the Twenty-First Century. American Society of Civil Engineers, New York, NY. 768 pages.

Link, S. O., R. J. Fellows, D. A. Cataldo, J. G. Droppo, and P. Van Voris. 1987. Estimation of Aerial Deposition and Foliar Uptake of Xenobiotics: Assessment of Current Models. PNL-6173/UC-11, Battelle Pacific Northwest Laboratory, Richland, WA 99352.

McCrady, J. K., C. McFarlane, and F. T. Lindstrom. 1987. The transport and affinity of substituted benzenes in soybean stems. J. Exp. Bot. 38(196):1875-1890.

McFarlane, C., C. Nolt, C. Wickliff, T. Pfleeger, R. Shimabuku, and M. McDowell. 1987. The uptake, distribution and metabolism of four organic chemicals by soybean plants and barley roots. Env. Tox. & Chem. 6:847-856.

McFarlane, C., T. Pfleeger, and J. S. Fletcher. 1987. Transpiration effect on the uptake and distribution of bromacil, nitrobenzene and phenol in soybean plants. J. Environ. Qual. 15(4):372-376.

McFarlane, C. and T. Pfleeger. 1986. Plant Exposure Laboratory and Chambers. U.S. Environmental Protection Agency, Corvalllis, OR. EPA/600/3-86/007a,b.

Pace, C. M. 1987. Ion Source Surface Activity in High Pressure Electron Capture Mass Spectrometry. Masters Thesis. December. Montana State University.

Randall, D. J., R. C. Russo, and R. V. Thurston. 1988. Ammonia distribution in and excretion by fishes. *In*: Fate and Effects of Pollutants on Aquatic Organisms and Ecosystems: Proceedings of the Ninth US-USSR Symposium, Athens, GA, October 19-21, 1987. R. C. Ryans (ed.). U.S. Environmental Protection Agency, Athens, GA. (In Press).

Russo, R. C., D. J. Randall, and R. V. Thurston. 1988. Ammonia toxicity and metabolism in fishes. *In*: Protection of River Basins, Lakes, and Estuaries: Fifteen Years of Cooperation Toward Solving Environmental Problems in the USSR and USA. R. C. Ryans (ed.). Special Publication, American Fisheries Society, Bethesda, MD. (In Press).

Suarez, L. A., M. C. Barber, and R. R. Lassiter. 1986. GETS, A Simulation Model for Dynamic Bioaccumulation of Nonpolar Organics by Gill Exchange: A Users Guide. U.S. Environmental Protection Agency, Athens, GA. EPA/600/3-86/057.

Thurston, R. V. and D. J. Randall. A respirometer with controlled water quality and computerized data acquisition for experiments with swimming fish. (submitted).

Wright, P. A., D. J. Randall, and S. E. Perry, II. Fish gill water boundary layer: A site of linkage between carbon dioxide and ammonia excretion. J. of Comp. Physiology. (submitted).

Wright, P. A., D. J. Randall, and C. M. Wood. The distribution of ammonia and H+ between tissue components in Lemon Sole (*Parophrys vetulus*) at rest, during hypercapnia, and following exercise. J. Exp. Biology. (submitted).

(D) Biotic Effects Analysis—lethal and sublethal consequences to individual organisms of a body burden of xenobiotic chemicals. In public health terms, this research corresponds most closely to dose-response assessment, although the transition from administered dose to tissue dose, i.e., direct study of the consequences of a specific body burden on morbidity and mortality, has not been accomplished. For ecological studies, the body burden must be computed because of the importance of food-chain transmission of chemicals in some systems. Given success in computation of body burden, the life-history consequences of exposure can be given a

significantly improved basis for modeling, prediction, and understanding.

Fletcher, J. S., F. L. Johnson, and C. McFarlane. Database assessment of phytotoxicity data published on terrestrial vascular plants. Soc. for Environ. Tox. and Chem. (submitted).

Johnson, F. L. and J. S. Fletcher. 1987. PHYTOTOX User's Manual. University of Oklahoma, Norman, OK.

Mayer, F. L., Jr. and M. R. Ellersieck. Experiences with single-species tests for acute toxic effects on freshwater organisms. Ambio. (accepted).

McFarlane, C. and T. Pfleeger. 1987. Plant exposure chambers for study of toxic chemical/plant interactions. J. Environ. Qual. 16(4):361-371.

(E) Population and Community Risk Assessment—consequences of realized biotic effects for the distribution and abundance of single-species populations and coupled population systems. This research draws, to some extent, on the results obtained in (C) and (D). Projects (E) are exploring diverse approaches to "Risk Characterization" for biotic communities, encompassing classic population matrices and birth/death process modeling through novel approaches attempting direct measures of the impact of pollutants on interspecific interactions.

De Luna, J. T. and T. G. Hallam. 1987. Effect of toxicants on populations: A qualitative approach. IV. Resource-consumer-toxicant models. Ecol. Modelling. 35:249-273.

Emlen, J. M. Terrestrial community models for ecological risk assessment: A state of the art review. Environ. Tox. and Chem. (submitted).

Emlen, J. M. Terrestrial population models for ecological risk assessment: A state of the art review. Environ. Tox. and Chem. (submitted).

Hallam, T. G., R. R. Lassiter, J. Li, and W. McKinney. 1988. Physiologically structured population models in risk assessment: *In*: Biomathematics and Related Computational Problems. L. Riccardi (ed.). Reidel, Hingham, MA.

Hallam, T. G., R. R. Lassiter, and S. A. L. M. Kooijman. 1988. Effects of toxicants on aquatic populations. *In*: Mathematical Ecology; II. Applications. S. A. Levin, T. G. Hallam, and L. J. Gross (eds.). Springer-Verlag, New York.

Hallam, T. G., R. R. Lassiter, J. Li, and L. A. Suarez. Modeling individuals employing an integrated energy response: Application to *Daphnia*. Ecology (submitted).

Hallam, T. G. and M. Zhien. 1987. On density and extinction in continuous population models. J. Math. Biol. 25:191-201.

Kelly, J. R. 1988. Ecotoxicology beyond sensitivity: A case study involving "unreasonableness" of environmental change. Chapter In: Ecotoxicology: Problems and Approaches, S. A. Levin, M. A. Harwell, J. R. Kelly, and K. D. Kimball (eds.), Springer-Verlag, New York. (In Press).

Kelly, J. R., T. W. Duke, M. A. Harwell, and C. C. Harwell. 1987. An ecosystem perspective on potential impacts of drilling fluid charges on seagrasses. Environ. Management 11(4):537-562.

Kelly, J. R. and M. A. Harwell. 1988. Indicators of ecosystem response and recovery. Chapter 2 In: Ecotoxicology: Problems and Approaches, S. A. Levin, et al. (eds.), Springer-Verlag, New York. (In Press).

Lassiter, R. R. and T. G. Hallam. Survival of the fattest: A theory for assessing acute effects of hydrophobic, reversibly acting chemicals on populations. Env. Tox. Chem. (submitted).

Li, J. 1988. Persistence and extinction in continuous age-structured population models. Int. J. Compt. Appl. Math. (accepted).

Li, J. 1988. Persistence in discrete age-structured population models. Bull. Math. Biol. (accepted).

Li, J. and T. G. Hallam. Survival in continuous structured population models. J. Math. Biol. (submitted).

Li, J., T. G. Hallam, and M. Zhien. 1987. Demographic variation and survival in discrete population models. IMA J. Math. Appl. in Med. and Biol. 4:237-246.

Logan, J. A. Derivation and analysis of composite models for insect populations. *In*: Estimation and Analysis of Insect Populations. L. L. McDonald, J. A. Lockwood, and J. A. Logan (eds.).

Morton, R. D. and S. O. Montgomery. 1988. Microcosm studies on the effects of drilling fluids on seagrass communities. *In*: 1988 International Conference on Drilling Wastes, Calgary, Canada. Elsevier. London. (In Press).

Wollkind, D. J., J. B. Collings, and J. A. Logan. 1988. Metastability in a temperature dependent model system for predator/prey mite outbreak interactions on fruit trees. Bull. of Math. Biol. (accepted).

Zhien, M. and T. G. Hallam. 1987. Effects of parameter fluctuations on community survival. Math. Biosci. 86:35-49.

(F) Ecosystem Risk Assessment—impacts of xenobiotic chemicals on multi-population systems, including processes expressed via their activities—primary and secondary productivity, biogeochemical element cycles, etc. These projects, like those of (E), can be classed under the rubric of "Risk Characterization," specifically in (F) dealing with risk to the structure and function of entire ecosystems.

Brezonik, P. L., L. A. Baker, J. R. Eaton, T. M. Frost, P. Garrison, T. K. Kratz, J. J. Magnuson, W. J. Rose, B. K. Shepard, W. A. Swenson, C. J. Watras, and K. E. Webster. 1986. Experimental acidification of Little Rock Lake, Wisconsin. Water, Air, and Soil Poll. 31:115-121.

Flum, T. F. and L. J. Shannon. 1987. The effects of three related amides on microecosystem stability. Ecotox. and Envir. Safety 13:239-252.

Glass, G. E., J. A. Sorensen, B. W. Liukkonen, G. R. Rapp, Jr., and O. L. Loucks. 1986. Ionic composition of acid lakes in relation to airborne

inputs and watershed characteristics. Water, Air, and Soil Poll. 31:1-15.
Niemi, G., S. Hedtke, R. Naiman, and J. Pastor. 1988. Quantification of disturbance, resistance, and resilience among ecological systems.
Rapp, G. Jr., B. Kiukkonen, J. D. Allert, J. A. Sorensen, G. E. Glass, and O. L. Loucks. 1987. Geologic and atmospheric input factors affecting watershed chemistry in upper Michigan. Environ. Geol. Water Sci. 9:155-171.
Rygiewicz, P., S. L. Miller, and D. M. Durall. 1988. A root-mycocosm for growing ectomycorrhizal hyphae apart from host roots while maintaining symbiotic integrity. Plant and Soil (accepted).
Shannon, L. J., M. C. Harrass, J. D Yount, and C. T. Walbridge. 1986. A comparison of mixed flask culture and standardized laboratory model ecosystems for toxicity testing. Pages 135-157 in J. Cairns, Jr. (ed.) Community toxicity testing, ASTM STP 920, American Society for Testing and Materials, Philadelphia.
Sorensen, J. A. and G. E. Glass. 1987. Ion and temperature dependence of electrical conductance for natural waters. Anal. Chem. 59:1594-1597.
Yount, J. D. and J. E. Richter. 1986. Effects of pentachlorophenol on periphyton communities in outdoor experimental streams. Arch. Environ. Contam. Toxicol. 15:51-60.
Yount, J. D. and L. J. Shanon. 1987. Effects of aniline and three derivatives on laboratory microecosystems. Environ. Toxicol. and Chem. 6:463-468.

Acknowledgment

Special assistance is provided to the Program Manager by the Advisory Committee, which is comprised of the research team leaders from all participating laboratories and OEPER Headquarters. The Advisory Committee includes Dr. Robert Swank, Athens Environmental Research Laboratory; Dr. Bill Williams, Corvallis Environmental Research Laboratory; Dr. Gerald Niemi, Duluth Environmental Research Laboratory; Dr. Foster Mayer, Gulf Breeze Environmental Research Laboratory; and Dr. Frederick Kutz, OEPER Headquarters.