UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C., 20460

OFFICE OF
PREVENTION, PESTICIDES AND TOXIC
SUBSTANCES

March 5, 2008

MEMORANDUM

SUBJECT: Transmittal of Meeting Minutes of the FIFRA Scientific Advisory Panel Meeting Held on December 4-7, 2007 to Review the Interpretation of the Ecological Significance of Atrazine Stream-Water Concentrations Using a Statistically-Designed Monitoring Program

TO: Debbie Edwards, Director
Office of Pesticide Programs

FROM: Jim Downing, Designated Federal Official
FIFRA Scientific Advisory Panel
Office of Science Coordination and Policy

THRU: Steven Knott, Executive Secretary
FIFRA Scientific Advisory Panel
Office of Science Coordination and Policy

Elizabeth Resek, Acting Director
Office of Science Coordination and Policy

Attached, are the meeting minutes of the FIFRA Scientific Advisory Panel open meeting held in Arlington, Virginia on December 4-7, 2007. This report addresses a set of scientific issues being considered by the Environmental Protection Agency pertaining to the Interpretation of the Ecological Significance of Atrazine Stream-Water Concentrations Using a Statistically-Designed Monitoring Program

Attachment

cc:

James B. Gulliford
James J. Jones
Anne Lindsay
William Jordan
Margie Fehrenbach
Donald Brady
Janet Andersen
Steven Bradbury
William Diamond
Tina Levine
Lois Rossi
Frank Sanders
Richard Keigwin
Enesta Jones
Vanessa Vu (SAB)
OPP Docket

FQPA Science Review Board Members

Steven G. Heeringa, Ph.D. (FIFRA SAP Chair)
John R. Bucher, Ph.D., D.A.B.T.
Janice E. Chambers, Ph.D.
Stuart Handwerger, M.D.
Gary Isom, Ph.D.
Kenneth M. Portier, Ph.D.
Daniel Schlenk, Ph.D.

FQPA Science Review Board Members

Xuefeng Chu, Ph.D.
William R. Effland, Ph.D.
Timothy R. Ellsworth, Ph.D.
James Fairchild, M.S.
Paige Gay, Ph.D.
Robert J. Gilliom, M.S
Christian Grue, Ph.D.
Thomas W. La Point, Ph.D.
Robert Lerch, Ph.D.
Jeffrey M. Novak, Ph.D.
James C. Randolph, Ph.D.
Linda J. Young, Ph.D.

SAP Minutes No. 2008-01

A Set of Scientific Issues Being Considered by the Environmental Protection Agency Regarding:

Interpretation of the Ecological Significance of Atrazine Stream-Water Concentrations Using a Statistically-Designed Monitoring Program

December 4-6, 2007
FIFRA Scientific Advisory Panel Meeting
held at the
Crowne Plaza - Washington National Airport Hotel
1489 Jefferson Davis Highway
Arlington, Virginia

Notice

These meeting minutes have been written as part of the activities of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), Scientific Advisory Panel (SAP). The meeting minutes represent the views and recommendations of the FIFRA SAP, not the United States Environmental Protection Agency (Agency). The content of the meeting minutes does not represent information approved or disseminated by the Agency. The meeting minutes have not been reviewed for approval by the Agency and, hence, the contents of these meeting minutes do not necessarily represent the views and policies of the Agency, nor of other agencies in the Executive Branch of the Federal Government, nor does mention of trade names or commercial products constitute a recommendation for use.

The FIFRA SAP is a Federal advisory committee operating in accordance with the Federal Advisory Committee Act and established under the provisions of FIFRA as amended by the Food Quality Protection Act (FQPA) of 1996. The FIFRA SAP provides advice, information, and recommendations to the Agency Administrator on pesticides and pesticide-related issues regarding the impact of regulatory actions on health and the environment. The Panel serves as the primary scientific peer review mechanism of the Environmental Protection Agency, Office of Pesticide Programs (OPP), and is structured to provide balanced expert assessment of pesticide and pesticide-related matters facing the Agency. FQPA Science Review Board members serve the FIFRA SAP on an ad hoc basis to assist in reviews conducted by the FIFRA SAP. Further information about FIFRA SAP reports and activities can be obtained from its website at http://www.epa.gov/scipoly/sap/ or the OPP Docket at (703) 305-5805. Interested persons are invited to contact Jim Downing, SAP Designated Federal Official, via e-mail at downing.jim@epa.gov.

In preparing these meeting minutes, the Panel carefully considered all information provided and presented by EPA, as well as information presented by public commenters. This document addresses the information provided and presented by EPA within the structure of the charge.

TABLE OF CONTENTS

SAP Minutes No. 2008-01

A Set of Scientific Issues Being Considered by the Environmental Protection Agency Regarding:

Interpretation of the Ecological Significance of Atrazine Stream-Water Concentrations Using a Statistically-Designed Monitoring Program

December 4-6, 2007
FIFRA Scientific Advisory Panel Meeting
held at the
Crowne Plaza - Washington National Airport Hotel
1489 Jefferson Davis Highway
Arlington, Virginia

Steven G. Heeringa, Ph.D.
FIFRA SAP Chair
FIFRA Scientific Advisory Panel
Date: MAR 5 2008

Jim Downing
Designated Federal Official
FIFRA Scientific Advisory Panel
Date: MAR 5 2008

Federal Insecticide, Fungicide, and Rodenticide Act
Scientific Advisory Panel Meeting
December 4-6, 2007

Interpretation of the Ecological Significance of Atrazine Stream-Water Concentrations Using a Statistically-Designed Monitoring Program

PARTICIPANTS

FIFRA SAP Chair

Steven G. Heeringa, Ph.D., Research Scientist & Director for Statistical Design, University of Michigan, Institute for Social Research, Ann Arbor, MI

Designated Federal Official

Jim Downing, FIFRA Scientific Advisory Panel, Office of Science Coordination and Policy, EPA

FIFRA Scientific Advisory Panel Members

Janice E. Chambers, Ph.D., D.A.B.T., A.T.S., Director, Center for Environmental Health Sciences, College of Veterinary Medicine, Mississippi State University, Mississippi State, MS

Stuart Handwerger, M.D., Professor of Pediatrics, University of Cincinnati Children's Hospital Medical Center, Cincinnati, OH

Gary E. Isom, Ph.D., Professor of Toxicology, Department of Medicinal Chemistry and Molecular Pharmacology, School of Pharmacy & Pharmaceutical Sciences, Purdue University West Lafayette, IN

Kenneth M. Portier, Ph.D., Program Director, Statistics and Evaluation Center, American Cancer Society, Atlanta, GA

Daniel Schlenk, Ph.D., Professor of Aquatic Ecotoxicology and Environmental Toxicology, Department of Environmental Sciences, University of California, Riverside, CA

FQPA Science Review Board Members

Xuefeng Chu, Ph.D., Assistant Professor and Research Scientist, Annis Water Resources Institute, Grand Valley State University, Muskegon, MI

William R. Effland, Ph.D., Soil Scientist, Resource Inventory and Assessment Division, United States Department of Agriculture (USDA) - Natural Resources Conservation Service, Beltsville, MD

Timothy R. Ellsworth, Ph.D., Associate Professor of Soil Physics, Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana, IL

James Fairchild, M.S., Research Aquatic Ecologist, United States Geological Survey (USGS), Columbia Environmental Research Center, Columbia, MO

Paige Gay, Ph.D., Assistant Research Scientist, Department of Biological & Agricultural Engineering, University of Georgia, Tifton, GA

Robert J. Gilliom, M.S., Chief, Pesticide National Synthesis, National Water Quality Assessment Program, USGS, Sacramento, CA

Christian Grue, Ph.D., Wildlife Research Biologist and Leader, Washington Cooperative Fish and Wildlife Research Unit, School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA

Thomas W. La Point, Ph.D., Professor and Director, Institute of Applied Sciences, University of North Texas, Denton, TX

Robert Lerch, Ph.D., Soil Scientist and Adjunct Assistant Professor, Department of Soil, Environmental and Atmospheric Sciences, University of Missouri, USDA/ARS, Cropping Systems and Water Quality Research Unit, Columbia, MO

Jeffrey M. Novak, Ph.D., Research Soil Scientist, USDA-ARS-Coastal Plains Soil, Water and Plant Research Center, Florence, SC

James C. Randolph, Ph.D., Professor and Director, Environmental Science Program, School of Public & Environmental Affairs, Indiana University, Bloomington, IN

Linda J. Young, Ph.D., Professor, Department of Statistics, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL

INTRODUCTION

The FIFRA Scientific Advisory Panel (SAP) has completed its review of the interpretation of the ecological significance of atrazine stream-water concentrations using a statistically-designed monitoring program. Advance notice of the SAP meeting was published in the *Federal Register* on September 19, 2007.

The FIFRA SAP review was conducted in an open panel meeting on December 4-6, 2007 in Arlington, Virginia. Dr. Steven G. Heeringa chaired the meeting. Jim Downing, EPA, served as the Designated Federal Official. William Jordan, Senior Policy Advisor, Office of Pesticide Programs (OPP), EPA, provided opening remarks at the meeting. Donald Brady, Acting Director of the Environmental Fate and Effects Division, OPP, EPA, provided an overview of the goals and objectives for the meeting. Stephanie Irene, Ph.D. of the Environmental Fate and Effects Division, OPP, EPA, gave an introduction and background. In addition, technical presentations of background materials were provided by Russell Erickson, Ph.D., of the Mid-Continent Ecology Division and Tony Olsen, Ph.D., of the Western Ecology Division, Office of Research and Development, EPA, along with Nelson Thurman, M.S. and Mark Corbin, M.S. of the Environmental Fate and Effects Division, OPP, EPA.

A risk assessment was conducted by the US Environmental Protection Agency (EPA) as part of the 2003 Interim Reregistration Eligibility Decision (IRED) on atrazine. The assessment indicated potential community and population-level risk to sensitive aquatic ecosystems at prolonged concentrations of atrazine from 10 – 20 parts per billion. As a condition of re-registration, atrazine registrants were required to develop a monitoring program to determine the extent to which atrazine concentrations in streams associated with corn and sorghum production may be exceeding levels that could cause effects to aquatic communities. If the thresholds were exceeded, then a watershed-based mitigation program could be required.

The atrazine exposure threshold was developed based on an analysis of the magnitude and duration of atrazine exposure that caused significant effects on various plants as reported in experimental microcosm and mesocosm studies. The primary endpoint of concern focused on impacts to the primary producers in the aquatic plant community and the subsequent impacts to the primary producer community structure. The Panel's evaluations are based on the premise defined by the Agency that plants are the most sensitive component of aquatic ecosystem that may be affected by atrazine toxicity, and thus that protection of plants will ensure protection of other aquatic organisms. However, an important caveat, recognized by the Panel and stated by the Agency, is that other types of effects that are not considered, such as reproductive or endocrine related, will be newly considered if evidence develops that they should be evaluated. As such, most aspects of the Panel's evaluation focused specifically on how effects on plant communities are addressed.

The monitoring program design was based on a population of 1,172 watersheds whose streams were identified as highly vulnerable to atrazine exposure based on factors such as atrazine use intensity in corn and sorghum production and run-off vulnerability. A sub-set of 40 of the 1,172 watersheds was selected for monitoring using a stratified, random statistical survey design, and within each of these 40 watersheds a sampling site was selected on a stream draining a sub-watershed that was thought to be dominated by agricultural land use. Streams were monitored for a minimum of two years with samples collected at least once every four days during the high-use season. Data from each stream were evaluated on a yearly basis to determine if atrazine concentrations were detected at sufficient levels over sufficiently long time durations to exceed the exposure threshold of concern. The intent is to use results from the streams in the 40 watersheds to make inferences about the larger population of 1,172 watersheds vulnerable to atrazine runoff.

PUBLIC COMMENTS

Oral presentations were given by:

Gary Marshall, CEO Environmental Resources Coalition (ERC)
Jere White on behalf of the Triazine Network, Kansas Corn Growers Association and Kansas Grain Sorghum Producers Association
Rick Robinson on behalf of the Iowa Farm Bureau
Richard Fawcett, Ph.D., Fawcett Consulting, on behalf of the Triazine Network
Danita Murray, National Corn Growers Association
Dr. Keith Soloman, Professor; Fellow of the Academy of Toxicological Sciences, University of Guelph, Dr. Steve Bartell, Office Manager and Principal Scientist, E2 Consulting Engineers, Inc., Dr. Dave Volz, Technical Expert, Ecological Toxicology, Syngenta Crop Protection, Inc., Dr. Paul Hendley, Science and Technical Senior Fellow, Syngenta Crop Protection, Inc., and Dr. Christopher Harbourt, Manager, Engineering, Waterborne Environmental, Inc., all on behalf of Syngenta Crop Protection
Dr. Dee Ann Staats, Environmental Science Policy Leader, CropLife America

Written statements were provided by:

B. Sachau, Florham Park, NJ

Tony Hawkes, National Marine Fisheries Service, NOAA

SUMMARY OF PANEL DISCUSSION AND RECOMMENDATIONS

The Panel recognized the intensity of the field monitoring effort resulting in the development of exposure time series (chemographs) dataset, which, together with community response data from a relatively large number of micro-and mesocosm studies provides opportunities to use these data pools in an aquatic community simulation model to determine if atrazine Levels-of-Concern (LOCs) are exceeded in Midwestern streams. The Comprehensive Aquatic Systems Model (CASM) was selected and tailored to perform atrazine risk assessments. The Panel was encouraged that the Agency uses CASM to relate atrazine exposure in the chemographs from the 40 watersheds to responses within the micro- and mesocosm studies. The use of Brock scores is conceptually an appealing approach, because of the broad scope of factors it theoretically captures in "processing" the exposure time series. CASM_Atrazine is designed to model field level biological responses, and is being considered by the Agency as a tool to relate field exposure (time series) to Brock scores (effects) based on the micro- and mesocosm community responses. The Panel saw incorporation of food web analysis and bioenergetics modeling as important additions to atrazine risk assessments. Food web analysis and bioenergetics modeling are currently being used to evaluate management strategies directed at stressors within aquatic systems; e.g. impacts of introduced species, or manipulations aimed at achieving targeted management objectives. Several Panel members asserted that the principal concern with the proposed use of CASM_Atrazine is the lack of validation of model outputs related to structural or functional effects reported in the environment or the micro-and mesocosm studies.

CASM_Atrazine is formulated and parameterized to represent 2nd and 3rd order Midwest U.S. stream systems. Specifically, physicochemical environmental input variables are primarily parameterized from an Ohio stream system. The Panel concluded that keeping the ecological modeling at the screening level is reasonable, a conclusion further enhanced by statistical analyses and supported by the extensive monitoring program reported for this assessment study on the ecological significance of atrazine contamination in Midwestern streams. The Panel discussed many of the ecological limitations and assumptions governing the bioenergetic-based equations in CASM_Atrazine. In particular, implicitly assumed in the model is complete mixing and that the ecosystem is homogeneous and uniformly responds to changes. These assumptions limit the model's applicability to some highly variable flowing stream systems. The Panel noted that even 2nd and 3rd order streams exhibit significant spatial variability and non-uniformity. As a result, the Panel recommended that the validity of these critical assumptions be verified before applying CASM_Atrazine to a real stream system.

The Panel recognized the significant efforts made by the Agency in evaluating the impact of input parameter uncertainties on CASM_Atrazine LOC estimates. However, based on the dynamics of ecosystem functioning in Midwestern streams under highly fluctuating environmental conditions and atrazine exposure, the Panel recommended additional evaluation of 1) the effects of interactions among physicochemical input variables, model parameters, and the monitoring data on uncertainty, and the extent to which uncertainties propagate through CASM_Atrazine into derived LOC values; and 2) how the intrinsic model parameters (e.g., rate coefficients, slope of the toxicity curve, EC_{50}, etc.) are likely to vary spatially. The sensitivity of results to the slope of the toxicity curve, as well as the EC_{50} values, should be examined to address possible effects on responses to short pulses of atrazine exposure. Additionally, the Panel recommended that a more explicit description be provided for the physical meaning of the annual average Steinhaus Similarity Index (SSI) and what relative changes in index values mean biologically. CASM_Atrazine outputs should include estimates, such as population structure, and biomass for the various simulated organisms.

The Panel agreed with EPA that off-season periods with extended low-level exposure to atrazine are an important condition. The Panel further agreed that improvements are required in order to develop methods for accurately monitoring exposure in such systems (including levels and duration), and also for assessing corresponding potential effects on aquatic communities. Furthermore, as agricultural management practices change over time, atrazine use and exposure may change in its seasonal duration (e.g., with increasing biofuel feedstock production, more acreage will likely be devoted to corn and atrazine use may increase). The Panel noted the low availability of empirical data on ecosystem response to prolonged low-level exposure to atrazine. Specifically, there is a gap in the micro/mesocosm data, since no testing was done for long durations of low level exposures of atrazine. The Panel recommended that the Agency implement additional assessment of these exposure conditions to help improve the understanding of the effects of low level, chronic exposures which may result in hometric (positive) responses, species adaptation, or species replacement. Such results may mitigate bioenergetic implications. In addition, the Agency should establish realistic early season conditions for model initiation and run the model starting earlier in the year.

The Panel was satisfied with the Agency's selection criteria used to identify final subwatershed and monitoring locations and agreed the justification for the use of the criteria are sound. The Watershed Regressions for Pesticide (WARP) methodology appears to be a logical approach to identify the areas of high vulnerability to atrazine exposures. The decision to use the 80-95th and >95th percentile WARP scores strata appears to be based on best professional judgment to insure that an adequate number of highly vulnerable sites were selected. The Panel agreed that the emphasis on hydrologic units (HUCs) more susceptible to atrazine runoff is appropriate, if little to no problem exists elsewhere. The Panel agreed that stratifying provides good information on the regions with higher atrazine concentrations (hot spots). However, for future monitoring efforts, some Panel members suggested that the plan to link WARP to the higher resolution GIS data may lessen the need to stratify the upper most (> 95%) atrazine exposures, thus the selection of further sites could be determined from upper portions of the cumulative distribution of sites ranked by CASM_Atrazine score as needed. Given that there will almost surely be some error in the ranking of most vulnerable sites using CASM_Atrazine scores, other Panel members believed that a probability-based design should continue to be used for future site selection.

The stream sampling sites within the HUC 10/11 were chosen based on sound reasoning considering access to the sites as well as costs. The Panel agreed that this is a prudent approach because the method encompasses samples from relatively large drainage areas and minimizes the uncertainty associated with sudden changes in cropping patterns or crop rotations. The limitations of only one data point per location can be overcome by grouping sites into similar land classes and comparisons with data from other studies. However, given the purpose of identifying sites with LOC exceedances, this design has the greatest power because it includes the largest number of sites for a given effort. The Panel suggested that the agency group locations from similar land classes. These exposure scenarios can be compared to long-term study sites such as the Heidelberg datasets or any of the numerous datasets located at the USDA-ARS stations across the Midwest.

For national coverage, the Panel suggested that the situation of no flow, low flow and intermittent flow sites should be further evaluated in the monitoring study. The sites in Nebraska have produced some of the highest atrazine concentrations measured during the study and, therefore, are important to understand and accurately predict atrazine exposure and effects at similar sites. The Panel recommended that the data need to be included, but treated separately until more monitoring or assessment of these sites can be accomplished. It was the general consensus of the Panel that the alteration in ecosystem food web and population response during no flow, low and intermittent flow conditions require further evaluation. It was noted that there is currently little empirical data to predict the effects of atrazine in intermittent streams. These changes would presumably alter bioenergetic parameters making comparisons to microcosms and mesocosm studies and compatibility with current CASM_Atrazine invalid. The Panel recommended that CASM_Atrazine be expanded to reflect parameters found in these low/intermittent-flow systems and the model be recalibrated and validated based on these altered bioenergetics equations.

The Panel was concerned with the apparent macrophyte sensitivity in a stream system relative to changes in the concentration of atrazine exposures. Results show that low to moderate SSI deviation following short-term, high atrazine exposure can be substantial and the variation in uncertainty associated with exposure measurements increases as the sampling interval increases. It was suggested that the 4-day sampling interval used was reasonable given knowledge of these systems at the time of study initiation. However, rainfall runoff events occurring between scheduled sampling days are likely the major source of uncertainty using the 4-day sampling regime. As reported, auto-sampler data of water flow suggested rainfall runoff peaks and subsequent exposures were being missed using only data from a 4-day sampling frequency. Further, atrazine exposure concentrations using the stair-step interpolation were inadequate. Both higher and lower rolling averages were demonstrated by including the auto-sampler data; however, it was also pointed out that the auto-sampler data were 6 to 8 hour composite samples, and as such result in a significant reduction in the magnitude of observed concentration peak values. The Panel recommended that a variable sampling interval, instead of a constant sampling time interval, would be preferable.

An uncertainty analysis was focused on model results as well as additional uncertainty attributed to the sampling interval and interpolation method. Panel members observe that some uncertainty is normally associated with Brock scores. Assuming that CASM_Atrazine employed by the Agency is correct, further uncertainty is associated with imprecise knowledge of model parameters. Sensitivity analyses were used to attribute a measure of 2X to this source of uncertainty; although the sensitivity analyses process appeared to be somewhat arbitrary to some Panel members. The safety factor may not account for chronic effects to non-target organisms. The Panel commented that the use of 2X does not include the uncertainty introduced by using 4-day grab samples to approximate a continuously changing level of atrazine.

The Panel appreciated the Agency's efforts to estimate the number of vulnerable watersheds that potentially exceed the LOC, with a corresponding estimate of reliability. Some Panelists were concerned that the Agency's use of the current selection criteria is insufficient for identification of stream segments/miles within these vulnerable watersheds that have LOC exceedances. In particular, it was pointed out that there is a pronounced impact of drainage scale on the observed atrazine chemographs, and that local fluctuations in atrazine levels are modulated with downstream distance. An example from Missouri was presented in which the both the rolling average concentration and duration exposure increased at down gradient locations in a watershed. As an alternative approach, the Panel recommended several steps that could be used by the Agency for a more accurate assessment of information concerning LOC exceedances in specific stream mile segments. It was proposed that national databases such as SSURSGO and especially NHDPlus will assist in this endeavor. Finally, a Panelist stressed the importance of including the representative range of scales needed to indicate all of the targeted stream miles within potential vulnerable watersheds.

The Panel recognized that the WARP model employs atrazine use intensity and its predictions are primarily driven by pesticide use per acre. The uncertainty associated with pesticide use data and WARP modeling necessitates using the best available atrazine use data to obtain accurate model predictions. The Panel recognized the economic limitation to extending sampling beyond the original 1,172 watersheds. However, it would be valuable to assess a broader atrazine use area, via GIS, involving those HUC 10 watersheds that were not included in the original 1,172 vulnerable watersheds yet which have a correspondence between relatively high atrazine use and the presence of soil restrictive layers, hydrologic soil groups C and D and relatively high runoff propensity indices. If other watersheds are not identified, then there would be even greater confidence in the original 1,172 watersheds selected. The Panel recommended the Agency consider revising the WARP model coefficients and parameters by re-running the step-wise regressions using the most current and accurate data. Temporal changes in atrazine use ranging from both short-term and long-term duration periods should also be considered in this analysis.

PANEL DELIBERATIONS AND RESPONSE TO CHARGE

The specific issues addressed by the Panel are keyed to the background documents, references, and the charge questions provided by EPA.

Question 1:

Please comment on the use of a community simulation model for assessing the relative effects of different exposure time series. Please provide any recommendations for a community response model other than, or along with, CASM that could be used for assessing the effects of atrazine. What are the strengths and weaknesses associated with the other model(s)? Please comment on approaches that do not require an aquatic community response model and discuss the advantages and disadvantages of any alternative non-modeling approaches for extrapolating the effects seen in micro/mesocosm data to the effects resulting from field exposure.

Panel Response

1. Model Selection: The Comprehensive Aquatic Systems Model (CASM) was selected and tailored to perform atrazine risk assessments for potential effects on aquatic plant communities. Given the choices of reasonably available models for this purpose, the Panel supported the selection of CASM. The Panel was less concerned with model selection than with how the model is parameterized, validated, and applied in the risk assessment process. With respect to the selection of CASM_Atrazine, however, it would be helpful to include justification for the focus on streams vs. other surface waters in the documentation, especially in light of the continuing controversy over the effects of atrazine on amphibians, which are more likely associated with other waters. Although the Agency addressed this issue in their opening remarks by more clearly describing the context in which the stream assessment is being conducted relative to other aquatic systems and endpoints, this context should be clearly articulated in future documentation.

With respect to approaches that do not require an aquatic community response model, such as criteria developed for specific, representative, or most sensitive species or taxa from species sensitivity distributions, the latter do not address community responses. These alternate approaches, however, may be more appropriate when specific species, or specific issues not directly related to primary producer community response, are the primary concern.

The use of CASM_Atrazine to relate the exposure to atrazine, as characterized by the chemographs from the 40 watersheds, to compute the Steinhaus Similarity Index (SSI), which is correlated with responses (effects of atrazine) observed in micro- and mesocosm studies (Brock scores), is conceptually an appealing approach to evaluating community response because of the broad scope of factors it theoretically captures in "processing" the exposure time series. In this application, CASM_Atrazine is an empirical tool used to relate field exposures (concentration time series) to Brock scores (effects) based on the micro/mesocosm community responses. The incorporation of food web analysis and bioenergetics modeling appears to be a useful addition to the atrazine risk assessment, because it enables computation of the SSI, which is correlated with Brock scores and can be used to distinguish acceptable or unacceptable ecological impacts, leading to specification of a LOC.

2. Validation: Although the model is being used to relate environmental exposure to an LOC, expressed in terms of the SSI value chosen from correlation with laboratory data, and not as an absolute measure of community change at particular sites, it is a model, and one in which ecological processes are being simulated. As such, the Panel was concerned about model calibration, transparency, and the interpretation of model outputs. For example, what does a particular deviation in the SSI translate to in terms of biomass of primary producers? What is the difference in primary production (and consumption) between sites that are substantially below the LOC vs. those that either exceed or approach the LOC? What are the potential chronic effects to non-target organisms? To what extent is the model conservative? Are "safety margins" adequate?

Related to these questions, a principal concern of the Panel with the use of CASM_Atrazine was the lack of validation analyses for either reference or exposure conditions to effects reported in the environment or in the microcosm and mesocosm studies. The Panel understood that there is an empirical comparison of percent SSI to Brock scores, but this alone did not yield sufficient confidence for several Panel members. A comparison of model outputs to results of ecological assessments at impacted and non-impacted stream ecosystems would help to alleviate concerns. The Panel recognized that atrazine occurs with many other stressors, and that sorting out specific cause and effect relations would be difficult, if not impossible. Nevertheless the Panel believed that some basic tests of consistency between predicted and actual conditions would be possible. An additional approach would be to validate the model by simulating results from selected mesocosm studies with the richest data sets. At a minimum, model outputs for primary producers and consumers should be presented for examples representing the range in SSI deviations and Brock scores.

The application of CASM_Atrazine (as currently constructed) to observed chemographs, with the intent of evaluating whether or not exceedances of the LOC have occurred, does not yet seem to be adequately supported. The model has not been shown to characterize ecosystem dynamics under rapidly fluctuating environmental conditions. In addition to the questions raised above regarding the ability of CASM_Atrazine to represent community dynamics in heterogeneous systems, there are also concerns regarding spatial scale effects. Several of these concerns are also discussed by Bulling et al. (2006), and quoted below:

> *"However, these high levels of control and replication mean that (micro/mesocosm) model system experiments are very specific to the system, organisms and experimental configuration being used. In turn, this specificity means that results are unlikely to be generally applicable across systems, or indeed between different configurations of the same system. In the same way, model systems are designed to focus on specific independent factors, allowing little understanding of the relative importance of these factors in relation to others in the full and more complex system."*

> *"These mechanisms work at the small, local scale, assuming that species interactions and their functional traits drive...the...relationship (Bengtsson et al., 2002). However, at larger spatial scales, it is likely to be variation in resources and abiotic factors that are the main drivers (Huston, 1994; Anderson, 1995)."*

The Panel recognized that it may not be feasible to do atrazine toxicity analyses for all selected sites under real conditions. Thus, a modeling approach that employs the existing atrazine toxicity data from microcosm/mesocosm studies is a natural choice for developing an LOC for ecological assessments. Yet there remains considerable uncertainty as to how these data should be used. The Agency has chosen CASM_Atrazine as the key means of relating these controlled system toxicity data to real world environments. Given that this is a bioenergetics process-based model, such a decision seems to be a move in the right direction, but questions remain regarding the applicability of this model to heterogeneous environments, and the Panel believed that these should be better addressed by the Agency.

These questions are supported by the lack of direct evidence that the model can simulate atrazine impacts in Midwestern streams. Despite a presentation to the Panel which demonstrated the general correspondence of CASM_Atrazine output with seasonal dynamics of several aquatic species in a lake, and the end of simulation comparisons with in-stream biomass, the Panel was not convinced that CASM_Atrazine can estimate the relative impact that would occur in typical Midwestern streams which have considerable diversity in physicochemical variables and community spatial structures. There needs to be more effort employed in the calibration and evaluation of the model for describing impacts in different stream environments under fluctuating atrazine-exposure profiles.

3. Transparency: Although Panel members support the decision to use a community effects model as a primary tool, several Panelists were concerned that the complex approach of using CASM_Atrazine to predict SSI, in order to compare to an LOC based on Brock Scores, will be exceptionally difficult for the public and managers to understand. Considering this concern, the Panel noted that CASM-atrazine could support the expression of the LOC in terms of either (1) percent SSI, as currently proposed, or (2) rolling average concentrations of atrazine (at selected time durations) that correspond to simulated SSI values.

4. Effects Not Addressed by CASM_Atrazine, SSI, and Brock Scores: The Panel noted that where specific species are the focus of risk assessments, (e.g., threatened or endangered species) both direct and indirect effects on the species of concern may be drivers and require multiple approaches to risk assessment. As noted above, criteria developed for specific, representative, or most sensitive species or taxa from species sensitivity distributions may be more important than community responses in these situations. Panel members noted that because of the mode of action of atrazine, which directly impacts aquatic plants and other primary producers, data for the latter should be protective of other taxa at least in terms of direct toxic effects. As the Agency has noted, fish and other aquatic organisms have much lower sensitivity to the acute effects of atrazine, including its transformation products, such that protection of plants should ensure protection of all organisms with regard to these types of toxic effects. Furthermore, the Agency has found that the atrazine parent compound is the primary chemical of concern for effects on plants because atrazine degradates are much less toxic to plants. In terms of standard toxicity assessments, these conclusions appear reasonable at this point in time. However, there is still uncertainty with regard to other types of possible effects; for example chronic effects to non-target organisms such as amphibians.

The Panel stressed, as the Agency has stated as well, that if new information becomes available about adverse effects of atrazine, these assumptions and the conclusions would need to be revisited. If this were to occur, the rôle of CASM_Atrazine may need to be re-evaluated, at least in terms of its ability to predict effects to more sensitive taxa or types of effects that it does not consider, such as interferences with reproductive functions, should they be a concern.

Question 2:

The general methodology employed in this analysis consists of (a) correlating model outputs to micro/mesocosm data to determine a model LOC and (b) applying the model to chemographs of interest to determine whether the LOC is exceeded. Please comment on the scientific strengths and limitations of this approach.

<u>Panel Response</u>

1. General Observations: The Agency and Registrant are fortunate to have a relatively extensive set of micro/mesocosm data to draw upon for determining a screening LOC. The LOC was determined by referencing CASM_Atrazine output (as the simulated annual average SSI deviation assuming the concentration-duration exposure occurred in a "typical" 2nd order Midwestern stream) to measured atrazine-induced effects and recovery rates of 77 effect scores (Brock scores) derived from 32 different experimental freshwater microcosm and mesocosm studies.

The Panel noted that the LOC determined from the relation between SSI and the Brock scores for the micro- and mesocosm studies is highly dependent on:

1) the quality of data reported within these studies, particularly studies yielding false negative or false positive CASM_Atrazine predictions,

2) the assumed similarity in community response between these relatively uniform micro/mesocosm systems and the actual, widely fluctuating systems that occur in Midwestern streams (see further comments below), and

3) the degree of conservativeness used to select an SSI that segregates good and bad Brock scores (for example, if a percent SSI had been selected for the LOC that was below all "unacceptable" Brock scores, the LOC would have been significantly lower).

2. Appropriateness of SSI and Brock Scores as Basis of LOC: The Panel was not clear on why the chosen CASM_Atrazine index, the average annual SSI, is optimal. Are there other indices determined by the model which would better reflect perturbations to ecosystem functioning? For any given day, the SSI provides a biomass weighted index of variation between reference and exposed communities. This daily index seems very appropriate; however, the procedure of creating an annual average of this value is not appropriate. For Midwestern streams, the Panel believed that species and total biomass would be considerably greater during the summer as compared to winter periods. For example, assume that aquatic stream biomass is 10 times greater in the summer than during December or January. With this assumption, a 10% SSI value on day 120 would represent a total biomass reduction that was 10 times greater than an equal SSI value on day 360, yet the current index would assign an equal weight to each. This inappropriately masks variations in biomass production. If an annual average value is desired, one possibility is to calculate differences in annual biomass production between disturbed and undisturbed systems for each aquatic species and use these values to compute an "annual" SSI. Another option is to weight the daily SSI values by total daily biomass, but this results in an index that is dominated by the most prevalent species. If such an index is to be used, it was suggested that the daily SSI values be weighted by the daily total biomass values. However, it is not clear if such an index is even what is desired.

The Panel further noted that the chosen CASM_Atrazine index does not distinguish between what seem to be highly contrasting experimental conditions. For example, consider the following two hypothetical exposure profiles. First, a daily 50% SSI value for 10 days, with a 0% SSI value for the remaining days of the year, and second, a value of 1.4% SSI for each day of the year. It seems that these scenarios reflect two highly contrasting impacts on the aquatic community, yet the chosen model index would not distinguish between such differences.

The micro/mesocosm based LOC index would likely work best with similar sets of taxa (periphyton, macrophytes, benthic algae, etc.). However, there may be an influence of one set of taxa (i.e., rooted macrophytes) that dominate the SSI deviations for a given concentration-duration exposure and stream environment, and thereby moderate the overall predictions of both annual SSI deviation and carbon produced per square meter. Plants are known to be leaky systems with respect to carbon, nitrogen and phosphorus. Hence, atrazine exposures for large plants will probably influence smaller photosynthetic organisms in decidedly non-linear ways. Many of the studies cited in Brock et al. (2000) used chlorophyll as an endpoint. As phytoplankton are small and respond quickly, the referenced model may be best suited to estimate impacts on algae.

Finally, the Panel raised a question for the Agency's consideration "How well will this approach work for risk assessment under conditions that differ from the referenced Ohio stream (e.g., other areas further west or in the southeast)? The Panel recommended that the Agency carefully address and explain these issues related to how well SSI, and Brock Scores represent the real-world effects of ultimate concern in a wide variety of streams. Clarity on these matters is critical to understanding the validity of the LOC.

3. Issues and Concerns Related to Representativeness of Micro/Mesocosm Studies: The validity of the LOC is ultimately dependent on the representativeness of the micro/mesocosm studies to real ecosystems. There may be variations in physicochemical factors between micro/mesocosm experiments that explain part of the overlap among Brock scores (e.g., daily temperature, light, dissolved inorganic nitrogen and dissolved inorganic phosphorous, etc.). These variations in factors that influence primary production among the datasets may possibly contribute to the "noise" in the Brock scores. Identifying such variations, if they exist, and then accounting for these differences may improve the correspondence between Brock scores and the CASM_Atrazine output, SSI.

Given that micro/mesocosm experiments are typified by average values of physicochemical variables, these experiments should correlate reasonably well with mathematical ecosystem models, such as CASM_Atrazine, that employ assumptions that responses can be expressed in terms of average values of light, nutrient levels, etc., and that spatial heterogeneities can be largely ignored. However, the highly variable spatial and temporal fluctuations in physicochemical properties and plant and animal species that would exist in a Midwestern stream (considering such factors as rainfall and stream flow variability and associated impacts on nutrient and suspended solids, etc.) would likely violate the assumptions implicit in the "homogenous" CASM_Atrazine. For example, the model simulates an aquatic community response in a vertical water column of one square meter, based on specific *daily* (assumed constant over a 24 hour period) input values of atrazine concentration, dissolved oxygen, inorganic nutrients, light, temperature, etc., a model which would be more appropriate for the uniformity encountered at a micro/mesocosm scale, in a lake, or a relatively well-mixed, slow moving water body. Yet in a typical Midwestern stream, these values vary significantly from moment to moment and over relatively small spatial distances. Even if these variations in input variables were known in detail, it is still not clear how to derive an "effective" or temporally and spatially averaged value of each input variable, that, when employed in CASM_Atrazine, would produce an effect that was similar to that which would occur in the spatially and temporally varying stream (this subject is the topic of the italicized citation below). CASM_Atrazine may be more appropriate as the watershed spatial scale increases and so too does the regularization of physicochemical attributes (i.e., less widely varying fluctuations in nutrients, atrazine concentrations, sediments, etc.).

In support of the preceding discussion, one Panel member offered the following quote from Bulling et al. (2006) concerning limitations of micro/mesocosm experiments and current mathematical models.

> *"A more subtle concern is that of mean field approximations (Petersen & Hastings, 2001). In the tight experimental design of many small-scale systems (e.g., micro/mesocosm), levels of environmental variables are approximated and constant, based on average levels of environmental factors (e.g. light, temperature, humidity). There is thus an implicit assumption that average levels of environmental factors, rather than their extreme levels or variability, determine ecosystem dynamics (Petersen & Hastings 2001). This may not be true and could lead to false conclusions being drawn from such experiments. However, mean field approximation can be an advantage in the integration of model systems with*

mathematical models and theory. Mathematical ecosystem models generally use mean field approximations for environmental variables, and there is therefore a close conceptual link between these types of approaches. This is particularly so for aquatic model systems (Petchey et al. 2002b). Mathematical models and theory often implicitly assume a closed system and a lack of spatial structure, the trademark of many aquatic (micro/mesocosm) model systems and quite different from most field experiments done in terrestrial systems. Reduced spatial environmental variation coupled with generally mobile individuals, leads to limited spatial aggregation of individuals and therefore dynamics approximating mean field conditions (Tilman et al., 2002)."

Question 3:

Please comment on the reasonableness of the general CASM_Atrazine model formulation and parameterization, and the various options selected for the base model configuration.

Panel Response

1. General Applicability of Approach: The bioenergetics-based CASM_Atrazine provides a biological and ecological modeling framework that describes population growth of aquatic plants and animals in surface water bodies in terms of daily biomass. CASM_Atrazine extends the capabilities of the Standard Water Column Model (SWACOM) (O'Neill et al. 1982; 1983) by including multiple populations of aquatic organisms that are characteristic of littoral and benthic communities. CASM_Atrazine, specially developed for this study, provides a way to understand how exposure to atrazine may affect populations in a community. The model uses a daily time-step to simulate production dynamics on an annual time scale. It calculates the biomass of primary producers by using equations describing physiological processes such as photosynthesis, grazing, nonpredatory death, respiration, etc. For consumer populations, consumption, egestion, nonpredatory death, respiration, and other processes are considered. CASM_Atrazine is formulated and parameterized to represent a second- or third-order Midwestern U.S. stream. The modeled aquatic community includes ten species of phytoplankton, ten species of periphyton, six species of macrophytes, two species of zooplankton, five species of benthic invertebrates, seven species of fish, and bacteria in both the water column and sediment. Physicochemical environmental input variables are primarily based on data for an Ohio stream.

Some Panel members noted that, considering the scope and objectives of the study, and the noted limitations of available data and CASM_Atrazine, it is most appropriate to keep the application of this ecological modeling at a screening-level (first phase of risk assessment). Subsequent phases of risk assessment should be further enhanced by statistical analyses and supported by monitoring, such as the extensive monitoring program in this assessment study on the ecological significance of atrazine contamination in Midwestern streams.

2. Model Assumptions and Limitations: Essentially, the governing equations for biomass production (bioenergetics-based equations) in CASM_Atrazine represent a dynamic system characterized by a set of first-order ordinary differential equations (ODE) with some nonlinear terms. Complete mixing is a major implicit assumption in the model. Thus, the water body (stream in this case) is assumed to be a homogeneous, well-mixed, lumped system. Any materials (water, sediments, atrazine, etc.) flowing into the system are instantaneously mixed with those existing in the system. Also, the corresponding homogeneous ecosystem uniformly responds to any changes. This type of model has been widely used for lakes and ponds. Applicability to highly variable, flowing stream systems (high spatial variability in hydrodynamics, atrazine levels, nutrient concentrations, temperature, light, etc.) is less tested and more uncertain. As observed by a Panel member, even for 2nd and 3rd order streams, the spatial variability and non-uniformity can be significant. Thus, the Panel recommended that validity of this critical assumption be verified before applying CASM_Atrazine to real stream systems.

In addition to the applicability of the model, the simulated system should be clearly specified. Currently, the model provides for no distinction between simulations and related assumptions for a pond or lake and simulations for a stream. For a part of a drainage system (e.g., 2nd and 3rd order streams considered in this study), all source and sink terms (inflow and outflow of mass) should be included in the governing equation. Specifically, the inflow from 1st to 2nd order streams and outflow from 3rd to 4th order streams should be included in the mass balance equations.

3. Validation and Parameterization Issues: Although several points were made related to validation in response to Question 1, this is a key issue for the Panel and additional elaboration is provided here along with the closely related discussion of parameterization.

CASM_Atrazine plays an important role in both atrazine-related ecological analyses and risk assessment for Midwestern streams in this modeling study. Panel members noted that since CASM_Atrazine is a process-based model, performance of the model needs to be validated. Its use in this study appears to be reasonable, but as with any model, calibration and validation of the model using real data should be a required condition of its use. This process-based ecological model involves a number of parameters and input data. Identification/determination of the parameters is a critical modeling step. The parameterization, as described in the documents provided, appears to work well for the conditions in the current generic model. In addition to the Ohio physicochemical parameters, however, the Panel believed site-specific parameters which are more suitable for other Midwestern streams should be identified and determined. The Panel could not evaluate this except through the relationship between model scores and the Brock scores.

One Panel member indicated that no information on the response of model outputs, as parameterized, for individual population components over time or their sensitivity to the reference stream conditions (Honey Creek) has been developed for the base model. Another panel member recommended that the correlation analysis should be used to at least selectively calibrate and validate the model with micro/mesocosm studies of atrazine effects to ensure that processes are reasonably represented.

The Panel stressed that without confidence in basic process simulation by CASM_Atrazine, the representation of responses to exposure over time will be in question. As other regions are assessed, further calibration and validation of the model will be needed. Further information and evaluation would build confidence in the model outputs. The Agency should consider that the dynamics of a stream system will have considerable direct and indirect influences on the ecological functions; these influences are not explicitly incorporated in the current CASM_Atrazine. The model does not consider the effect of suspended sediments on light conditions and the effect of scouring on periphyton populations. Since this study focuses on 2nd and 3rd order Midwestern streams, the hydrographs of such small streams/creeks are often characterized by a number of short-duration storm peaks. They can be much shorter than the daily time step in the modeling (24 hours), depending on rainfall, land use/covers, soils, topography, and other conditions. The effects of these small scale hydrologic processes on the ecological functions also should be considered by the Agency because of their importance in the monitoring design as well as in the modeling efforts.

Question 4:

Please comment on whether the described sensitivity analyses are suitable for characterizing uncertainties associated with the choice of options for configuration of the base model and the input variables. What additional sources of uncertainty alternatives should be examined in this analysis? Please comment on whether the sensitivity of results to the slope of the toxicity curve, as well as the EC_{50}, should be examined to address possible effects on responses to short pulses.

Panel Response

1. General Observations: Sensitivity analysis is a traditional method of exploring and quantifying the sensitivity of changes in the results to specified variations in selected model variables, typically the "driving" variables. Whether intentional or unintentional, model results can be markedly different because of a highly sensitive variable. Conversely, variation in the value of other variables within a reasonable range, say doubling and halving the original value, may result in little or no change in the model results.

The Panel recognized the significant effort that the Agency has made in evaluating the impact of various sources of input uncertainty on CASM_Atrazine estimates of LOCs. If it is accepted that CASM_Atrazine provides an appropriate description of the dynamics of ecosystem functioning in Midwestern streams under highly fluctuating environmental conditions and atrazine exposure, then additional work is required to evaluate the issue of interaction among uncertainties associated with model reference conditions (Honey Creek), physicochemical input variables, model parameters, and the monitoring data and how such uncertainties propagate through CASM_Atrazine into uncertainty in LOC values. As discussed in the Agency white paper, such a sensitivity analysis will provide important benefits.

2. Model Configuration and Parameterization: If relative effects are sufficiently similar across a range of possible model configurations, the need to independently justify specific options for model configuration is reduced. The Panel noted that so far, the Agency has included parts of CASM_Atrazine in the sensitivity analysis. Specifically, these include:

(a) *The selection of the model effects index.* The sensitivity analysis contrasts the multiplication factors for two alternative effects indices (AVP and MXS –although the actual names are undefined in the text) with the model effects index for the base model configuration. Although the AVP index had a lower LOC and the MXS index had a higher LOC, the resulting multiplication factors for all model configurations were approximately the same. Thus, this analysis, which uses several distinct effects index choices, suggests that the choice of model effects index does not affect the results of the analysis. However, this approach ignores possible interactions between the effects index and other model parameters and input variables. In addition, it is not clear whether the conclusions would change if a different effects index were employed as suggested above.

(b) *The start date for model simulations of the micro/mesocosm exposures.* The first significant atrazine exposure will vary according to both rainfall and agricultural practices. The start date for the model exposure was selected as DOY 105 (April 15). Start dates 15 days before and 15 days after the base choice were tested. There was little variation or change in the CASM_Atrazine model results relative to the choice of the three start dates. However, an important question concerns the range of dates. One Panel member inquired if the Agency has considered whether these dates are representative for sites across the Midwest, recognizing that precipitation patterns and agricultural practices (e.g., corn and sorghum planting dates) are variable across the region.

(c) *The environmental driving variables (nutrients, temperature, and light).* The sensitivity analysis of the base model configuration with physical/environmental data (nutrients, light, and temperature) requires more attention. The sensitivity analysis altered nutrients, increasing or decreasing, by a factor of two. Temperature was increased or decreased by 5° C and light was doubled or halved. Rather surprisingly, the resulting multiplication factors were never more than 20% different from those in the base model configuration. Various interactions among these physical/environmental variables apparently were not investigated. The Panel recommended a joint sensitivity analysis which examines not only the effects associated with individual factors, but the effects of interactions among these factors.

(d) *The EC_{50} selection.* Ten alternative sets of plant EC_{50} values were randomly selected from a log-normal distribution with a median concentration of 100 μg/L. The mean and standard deviation of the multiplication factors for the alternative plant EC_{50} sets were compared to the multiplication factors for the base model configuration. The results show greater deviations from the base case, but as found in earlier analyses, were not greatly different.

3. Lack of Model Sensitivity: The Agency assumes that a lack of sensitivity in model simulated LOCs across a range of possibilities in simulated system properties increases the confidence that extrapolations among natural systems also would not be highly sensitive to system properties. This may be a reasonable assumption, but is not fully explored in this analysis. Additional benefits of a sensitivity analysis will provide some quantitative information on certain sources of uncertainty, which can inform risk management decisions for assessments with exposures near the LOC. One Panel member inquired whether the Agency had considered examining additional sources of uncertainty, as well as interactions among these. If the model is to be applied in a generic fashion for any Midwestern stream, then the variability in physicochemical parameters encountered within Corn Belt streams should be accounted for in this analysis, as should the chemograph uncertainties. As mentioned above, an examination of selected interactions among physical/environmental variables is highly desirable. It is also unclear what the sensitivity of model results is to choice of the reference stream, Honey Creek. At least one Panelist was concerned that the lack of sensitivity presented by the Agency may not be desirable if it occurs because the model does not respond to the different conditions that occur in different streams.

4. Additional Sensitivity Issues: The Panel suggested that there are likely spatial variations in the intrinsic model parameters (e.g., rate coefficients, slope of the toxicity curve,

EC_{50}, etc.). The sensitivity of results to the slope of the toxicity curve, as well as the EC_{50}s, should be examined to address possible effects on responses to short pulses. The Panel encouraged an expanded literature review to estimate the likely magnitude of the slope of the toxicity curve, such as has been done for the EC_{50}. Such an analysis would increase the understanding of what sources of input uncertainty are most critical with respect to quantifying LOC values. In Xu, et al. (2007), a method of assessing ecosystem model output uncertainties in response to various input uncertainties, with a similar application as that being sought for CASM_Atrazine, is discussed:

> "*Owing to two recent important extensions to Fourier Amplitude Sensitivity Testing (FAST) (Tarantola et al., 2006, Xu and Gertner 2007a, 2007b), a popular uncertainty and sensitivity analysis technique originally developed by Cukier et al. (1978), we are able to conduct the uncertainty and sensitivity analysis of community and ecosystem response to climatic change with complex nonlinear process and dependent model inputs.*"

Additionally, the Panel recommended that the physical meaning of the SSI and relative changes in index values should be more explicitly described in the context of sensitivity analysis. Review of CASM_Atrazine output should provide estimates of biophysical data (such as organism populations or grams of biomass carbon per square meter) for the various simulated organisms. These data could be graphed or tabulated to help visualize and explain SSI relative changes from values of 2 to 4 to 6 or 8.

The Panel recognized the achievement of Agency staff and their knowledge of model sensitivity and also recognized that they will be the most authoritative to clarify the model. The Panel recommended that potential modifications to the model should be documented to address deficiencies and an explanation for each of the revisions added to the model documentation.

Question 5:

During its review of CASM_Atrazine, the Agency found that the model appears to overestimate the effects of low, chronic concentrations possibly due to the way the model simulates population levels and decline of macrophytes early in the year.

- o The Agency sees two approaches for addressing this issue: (1) exclude early season atrazine exposures from the chemograph inputs, or (2) modify the model to better account for the impacts of early-season exposures. Please comment on the strengths and weaknesses of the Agency's approaches and provide recommendations for any alternatives.
- o Given that the Agency identified this issue during the exposure evaluation, please provide recommendations on additional steps the Agency could take for quality assurance for the model and methodology.

<u>**Panel Response**</u>

1. Importance of "Off-Season" Periods: The Panel recommended that off-season periods with extended low-level exposure to atrazine be considered by the Agency as an important condition to understand in terms of both exposure, including levels and duration, and potential effects on the aquatic community. This condition is characteristic of a substantial portion of the year, spanning a wide range of life stages of various organisms in the aquatic community. Furthermore, as agricultural management practices change over time, atrazine use and exposure may change in its seasonal distribution. In addition, should new information become available on effects of atrazine on aquatic animals, such as reproductive functions, the exposure assessment will be most relevant and useful if the entire year is characterized.

2. Annual Chemograph: Because of the importance of including the off-season periods in the assessment of exposure and effects, the early season exposure levels should be retained in the annual chemograph. It is important to start with a realistic characterization of early season exposure levels and durations, keeping in mind that seasonal use patterns can change over time as weed control strategies evolve. The lack of off-season monitoring in the Atrazine Ecological Exposure Monitoring Program (AEEMP) hampers this, but existing data from other monitoring programs could be used to make realistic estimates. Early-season sampling at selected AEEMP sites could be added to verify assumptions.

3. Model Performance: In addition to improving the characterization of early-season exposure, the Panel recommended that it should be demonstrated that the CASM_Atrazine approach can begin the simulation year with realistic initial conditions and reasonably simulate processes during the early season. This relates to how initial conditions, derived from the single reference system in Ohio, are represented in the model such that the low-level exposures at the start of the year are evaluated against the correct biomass status of the ecosystem. The apparent problem with representing the biomass status and the associated SSI, particularly related to macrophytes, needs to be corrected. The problem may be related to simulated macrophyte loss due to some combination of exposure estimates and macrophyte sensitivity. The Panel recognized that the Agency staff and the registrant are working on the problem.

4. Sparse Data on Ecological Response: In addition to problems with the model simulation of early season conditions, the Panel noted the low availability of empirical data on ecosystem response to prolonged low-level exposure. Specifically, there is a gap in the micro/mesocosm studies with regard to long durations (i.e., 260 days) of moderately low exposures of atrazine. The Panel recommended that the Agency consider taking steps to provide additional assessment of these exposure conditions as part of improving the understanding of the effect of low level, but chronic concentrations.

Question 6:

The monitoring program used a tool (WARP) designed to assess the vulnerability of watersheds and stream segments to (1) identify watersheds within the corn/sorghum growing region that are likely to be most vulnerable to atrazine exposure and, (2) select sampling sites within the watersheds that are likely to be more susceptible to atrazine runoff.

- Please comment on the use of WARP predictions for hydrologic units (HUC 10/11) to restrict the survey design to those HUCs in the upper 20^th^ percentile and then (1) to stratify by WARP predictions between 80^th^ – 95th percentiles and above 95^th^ percentile and (2) to select HUCs with probability proportional to higher atrazine use rates.
- Comment on the use of survey design population estimation approach for estimating the number (and %) of HUCs that may have LOC exceedances.

Panel Response

1. General Observations: The Panel commended the Agency on its effort to combine scientific understanding of watershed vulnerability with a probability-based sampling program. The selection criteria appeared to be satisfactory for final subwatershed and monitoring locations and the justification for the use of the criteria was sound. WARP appears to be a logical approach to identify the areas of high vulnerability to atrazine exposures. The original model was based on USGS data derived from 112 river and stream stations from both the National Stream Quality Accounting Network (NASQAN) and National Water-Quality Assessment (NAWQA) programs. The size of the watersheds used for model development spanned a wide range (from 6 – to over 1,000,000 sq. miles) and the model was developed nationally and not only for the Midwest. In spite of the broad scope of the watersheds, Larson et al. (2004) reported that the model predicted 62-77% of the variation of atrazine concentrations in surface waters.

2. Effectiveness of Stratification: The Panel noted that the model effectively reduced approximately 6,000 HUCs down to the pool of 1,172 possible units at or above the 80^{th} percentile of WARP scores. Parallel comparisons to other approaches for identification of highly vulnerable areas to atrazine exposure were made using the Minnesota Erodability Index; data from the Natural Resources Conservation Service (NRCS) soil ratings; flow accumulations from the National Elevation Dataset (NED) and National Land Cover Dataset (NLCD); and actual surface water datasets for atrazine that showed a high level of redundancy in predictions. The decision to stratify between the $80\text{-}95^{th}$ and $>95^{th}$ WARP scores appears to be based on professional judgment in order to insure that an adequate number of highly vulnerable sites were selected. The emphasis on the more susceptible HUCs is appropriate. If the atrazine impact is assessed to be minor in these situations, it is very likely that the risks will be acceptable at the remaining sites. That said, the Panel recognizes that the general relationships expressed in WARP may not account for site-specific characteristics which impact atrazine runoff (e.g., the relationship that the Registrant identified between the presence of restricted soil layers and an increase in atrazine runoff).

As to the further stratification, the Panel agreed that stratifying provides good information on the upper bounds of atrazine concentrations (the hot spots). For future monitoring efforts, some Panel members suggested that the plan to link WARP to the newer GIS-based stream segments may lessen the need to stratify the upper most (> 95%) of atrazine concentrations. Thus the selection of further sites, if and as needed, could be taken off the upper portions of the cumulative distribution of sites ranked by WARP score. Given that there will always be uncertainty in the ranking of most vulnerable sites using WARP scores, other Panel members believe that a probability-based design should continue to be used for site selection, and that it should include some sites with lower scores.

3. Representativeness: In terms of representation, the Panel was also impressed by how closely (Sielken and Valdez-Flores report) the sample distribution of WARP scores based on a random sample of 20 from the 847 WARP scores in the 80th-95th percentiles matches the population distribution of WARP scores from those 874 sites, and by how closely the sample distribution of 20 sampled WARP scores from the 298 WARP scores lying above the 95th percentile matches the population distribution of WARP scores from those 298 sites. Statistical analyses, such as canonical correlation of the 34 site characteristics may lead to identification and characterization of the watersheds that are most closely associated with atrazine runoff and/or stream concentrations.

4. Improved Geographic Analysis: The Panel recognized that the stratification of the most vulnerable watersheds was based on the best available knowledge at the time of study initiation and that analytical challenges would arise in revising the strata. At the same time, resources that could better identify the most vulnerable watersheds are now available. The Panel recommended that the Agency continue to explore the availability of more accurate and precise GIS data and if the subsequent analytical challenges can be addressed, revise the stratification of vulnerable watersheds using the most current and accurate data available.

The WARP model developed by USGS (Larson et al. 2004) is a multiple regression model with its "most important explanatory variable" being "atrazine use intensity" (amount of atrazine used in a watershed divided by the area of the watershed). Because the WARP model is primarily driven by the use data, having the most accurate atrazine use data (both spatially and temporally) is important. Coupling the WARP parameters with updated atrazine use intensities and using the National Hydrography Database (NHDPlus) may provide a useful means of identifying potential vulnerable areas based on both current use and on projections of changing use (for instance, increasing acreage planted in corn because of demands for ethanol). This tool, coupled with the results of the monitoring study, could prove useful in identifying areas in which future monitoring efforts for atrazine could be targeted.

5. Statistical Issues with Survey Design and Interpretation: With respect to the survey design the Panel appreciated the need to use a design that led to spatial representativeness and produced unbiased estimates. The generalized random tessellation stratified (GRTS) design, used in this study, achieves these goals, has been used by the Agency in a number of previous studies, and has been vetted through the peer-review process (Stevens and Olsen, 1999; Stevens and Olsen, 2004). As noted above, sampling from two strata comprised of watersheds in (1) the 80 to 95th percentile of vulnerability and (2) above the 95th percentile of vulnerability, focused sampling on the most vulnerable watersheds. The selection of HUCs with probability proportional to atrazine use was designed to further target sampling toward vulnerable watersheds, which makes sense scientifically. Because the stratification had some error, this weighting process may not have improved the precision of the estimates. However, because the estimates are based on a probabilistic sample, the estimates continue to be valid, though they may be less efficient.

The survey design can be used to estimate without bias the numbers of HUCs that have LOC exceedances. The use of only the 20% of most vulnerable watershed makes the proper interpretation and communication of results challenging. It is the number and percentage of HUCs within the restricted population of the 20% most vulnerable HUCs that have at least some area with an LOC exceedence that is being estimated. Translating these values to the population of all HUCs might allow for better understanding of the results.

Question 7:

Once the vulnerable HUC 10/11 watersheds were selected for monitoring, specific monitoring sites were selected within each watershed using criteria that were designed to maximize the potential for selecting the streams most vulnerable to atrazine exposure. However, with only a single point monitored per watershed, estimates of within-HUC variability for detections of atrazine could not be calculated. The resulting population estimates reflect variability across watersheds but not within the monitored watersheds. Please comment on this approach and identify and discuss any alternative approaches to extend the results of the monitoring sites.

Panel Response

1. General Observations: The Panel noted that the Agency staff arrived at a selection decision of a single sampling site within each HUC. Given that the goal of the study is to identify the number of watersheds with at least one site exceeding the LOC, this is a reasonable sampling design. Additional sites within a HUC would allow the variability within a HUC to be quantified, but given the same level of resources, it would have been at the expense of sampling more HUCs. Thus, the precision with which the number (and percentage) of HUCs with at least one point exceeding the LOC is maximized with the design used by the Agency. Of course, the trade-off is a lack of information on the variability within a HUC.

2. Site Selection: As noted, standardized methods were used to locate the actual sample site at the lowest end of the selected stream segment (yet adjusted upstream in some instances based on a decision tree). The process probably minimizes bias across sampling units and assures that the location will include the resulting atrazine inputs for all possible locations from tributaries located upstream of the sampling point and in the subwatershed of the HUC that is associated with selected stream segment. The Panel agreed that this is a prudent approach because the method encompasses samples from the largest drainage area possible associated with the selected segment and minimizes the uncertainty associated with sudden changes in cropping patterns or crop rotations.

3. Within HUC Variability: In order to assess within HUC variability, the Panel recommended that the Agency examine individual subwatershed datasets in parallel with research information from long-term study sites such as the Heidelberg Lake Erie Watershed datasets or any of the numerous datasets located at USDA/ARS stations across the Midwest. For example, one of the Missouri sites, Youngs Creek, lies within the Goodwater Creek watershed, a location previously well-researched by USAD-ARS scientists. Additionally, many of the HUCs will lie near NAWQA sites. For example, the Wolf Creek, Iowa site lies within the Eastern Iowa NAWQA Basin. Furthermore, datasets from USGS gauging stations may be accessed to provide long-term data regarding rainfall, fluvial stage, and discharge relationships. In each of these instances, the Panel suggested that a pool of data already exists that can be examined and compared to the site-specific AEEMP data. Hypotheses can be generated from observations, which may provide opportunities for future collaborative studies on atrazine, in addition to other substances of concern, for example nitrates.

4. Scale and Representativeness: Scale is an important issue that affects the concentration-duration of exposure, but the key question is not how well the chosen site represents the HUC, but how it fits into characterizing the entire targeted population of streams of interest. In particular, other factors equal, small streams tend to have much higher upper percentiles of concentrations (higher acute conditions) than large streams, whereas the time-weighted annual means, or other longer-duration rolling averages, may be about the same (if monitoring is sufficiently intense). Panel discussions during the meeting indicated that the full range of stream scales including intermittent streams is important to consider and incorporate in order to meet Agency objectives (see Question 8).

The questions are (1) how well has the AEEMP characterized the chosen scale (10-50 square mile watersheds) under the defined conditions, and (2) how are the findings for this scale related to smaller and larger watersheds so that broad interpretations can be made? The HUC scale was used to allocate sites, but is not critical to interpretation for the scale of the sampled sites. This means that decisions must be made about the targeted scale in relation to the significance of the aquatic ecosystem. Is one scale more important than another? Where is the break point? Based on these decisions, priorities can be established for using modeling and additional monitoring to link the scale focused on by AEEMP to other objectives.

Question 8:

Three monitoring sites in NE experienced low- or no-flow conditions that precluded sampling. While Hampton et al. (2007a) suggest that these sites with intermittent or low flow are already stressed by other factors; Meyer et al. (2007) indicate that such aquatic communities are rich in diversity. The Agency has generated statistics for these three sites as a separate stratum; however the meaning of these separate population estimates is uncertain.

- Please comment on whether the Agency should consider the low flow sites and/or intermittent streams as a part of the population estimates or treat them separately.
- Please comment on whether the aquatic systems and exposure conditions of the existing microcosm and mesocosm studies adequately represent these low flow and/or intermittent stream communities. If not, how could EPA determine an LOC for low flow conditions?

<u>Panel Response</u>

1. General Observations: The Panel agreed with the Agency's decision that to be representative of the vulnerability of watersheds to atrazine concentrations at the national level, the no-flow, low-flow, and intermittent-flow sites should be included in the monitoring study and for continued consideration. These sites have produced some of the highest atrazine concentrations measured during the study and, therefore, are important to understand and accurately predict atrazine transport behavior at similar sites.

2. Inclusion, But Also Separate Consideration: As presented by the Agency, most Panelists recommended that the data for these sites be included, but treated separately until more monitoring or assessment of these sites can be accomplished. Some Panel members, however, suggested that if the atrazine concentration data were collected during the typical planting window and the flow data were within the 25^{th} and 75^{th} percentiles, then the sites should be included in the larger pool of streams rather than be treated separately. These parameters would be met with sites NE 05 and NE 07, but it is questionable whether enough data were collected for site NE 04 to determine if it meets these criteria.

3. Stream Flow Data: The Agency did not make it clear to the Panel why these sites were not ranked among the lowest of the 40 monitored sites in terms of stream flow. Flow at two of the sites (NE 05 and NE 07) was measured as having continuous and approximately average flow. However, on several scheduled 4-day sampling events, no sample was collected and the failure to collect a sample was documented as low or no-flow. As noted in the following paragraph, the accuracy of the flow measurements taken at these sites is rather poor, being determined as a function of stream depth and estimated stream bed characteristics. Again, as higher concentrations of atrazine were measured at these sites, flow data are essential to reference concentration and exposure. The Panel questioned whether there could be an upstream agent causing low-flow conditions.

The Panel was provided insight by the registrant's contractor who indicated that proper measurement of stream flow depths may have been difficult due to channelizing of flow during low-flow conditions. Also, flow measurements were based on stream bed characterizations, which would be difficult to define during channelized low and intermittent-flow conditions.

4. Flowing vs Non-flowing Conditions: It was the general consensus of the Panel that the alteration in the ecosystem during no-flow, and intermittent-flow rendered direct comparisons to perennial flowing systems unreliable. Flowing water distributes many of the chemical and physical life sustaining variables to aquatic biota. Intermittent low flow can limit nutrients available and may lead to increases in water temperature. Both have potential to serve as stress factors to the entire ecosystem and possibly affect consumer/producer populations and thus biomass production. These changes would presumably alter bioenergetic parameters making comparisons to microcosm and mesocosm studies and compatibility with the current CASM_Atrazine invalid. It is suggested that CASM_Atrazine be retooled to reflect parameters found in these stressed low/intermittent flow streams and the model be recalibrated and validated based on these altered bioenergetics equations. Currently, CASM_Atrazine is referenced to flowing water systems and as such excludes these sites from being incorporated into the dataset.

The Panel suggested an alternative approach of using the current dataset. The rationale for this alternate approach was that stream biota may be adapted to periods of no to intermittent-flow conditions. If this is indeed true, then the stream biota may not be stressed, but in fact may thrive. The organisms of interest would likely be small and able to respond and recolonize quickly. The Panel suggested that a cumulative distribution could be used to model the amount of time a stream is flowing and the duration of ponded water in a stream. The degree of intermittency would then be reflected in the number and kinds of aquatic species present. As noted by the Panel, this type of model (Huston, 1979 and 1994) could be used to link the responses of groups of species to the degree of stress brought about by environmental conditions. The model might then provide an index of biotic community responses in the low or intermittent streams for correlation to the results of the mesocosm tests and Brock scores.

The microcosm and mesocosm studies used to calibrate CASM_Atrazine included some stagnant systems, simulated stream systems, and recirculating systems. One Panel member suggested that periods of no-flow in the streams would be represented by the stagnant microcosm and mesocosm studies. As such, the LOC determined for all streams in the study could be applied even if it were a high concentration that was interpolated in a stair step method until another sample was successfully obtained. Caution is advised, however, because interpolation of concentrations across gaps where samples were not available can produce grossly exaggerated values, particularly since some of the higher concentrations measured occurred prior to a sampling gap. In addition, intermittent rainfall event driven flows might have occurred between the 4-day sampling site visits which produced uncaptured flow.

5. Alternative Approach: One final approach suggested by two Panel members was to use empirical data rather than data from the model. Using the existing microcosm and mesocosm studies, a time interval approximating the conditions of a no-flow or intermittent-flow stream could then be identified and serve as an initial screening method. Though there was some divergence of recommendations by Panel members, the majority agreed additional monitoring and or assessment would be required to fully understand the response and exposure issues related to extremely low-flow, and intermittent-flow streams and to determine an appropriate LOC.

Question 9:

The monitoring study sampled for atrazine concentrations at 4-day intervals to characterize the atrazine chemograph in these low-order Midwestern streams. CASM_Atrazine used these chemographs with a stair-step interpolation between samples dates to relate atrazine exposures in the streams to microcosm/mesocosm studies in order to determine whether the exposures triggered LOC thresholds.

- What other approaches for interpolation should be considered? Given the concentration-duration endpoint, how frequently must sampling occur to appropriately capture the magnitude and durations of exposure associated with atrazine?
- Sensitivity analysis of CASM_Atrazine inputs suggests that some uncertainty bound on model results is appropriate. The Agency used a 2x multiplication factor from the model sensitivity analysis to estimate uncertainty in model output. The sample frequency analysis indicates that there is uncertainty associated with monitoring data that may not be accounted for by the model uncertainty factor of 2X. Given the importance of sample frequency and interpolation, please comment on whether consideration should be given to placing additional uncertainty bounds on monitoring data to account for uncertainty in the ability of the sampling strategy to capture the magnitude and duration of atrazine exposures. Please provide any suggestions for how to proceed with this approach.

Panel Response

1. Sensitivity to Short-Term Exposure: The sensitivity of a stream system to concentration exposure duration directly determines the importance of properly accounting for this condition. Results show that short-term exposures can have substantial ecological effects, particularly at low to moderate SSI deviations. Further, as shown with the Heidelberg College data, the variation and uncertainty associated with estimated exposure time series and statistics increases as the sampling interval increases. The 4-day sampling interval used here was labor intensive and a reasonable one at study initiation. However, rain-produced runoff or irrigation events occurring between scheduled sampling days are likely the major source of uncertainty using the 4-day sampling regime. The addition of auto-sampler data to atrazine profiles suggested that event peaks were being missed using a 4-day sampling frequency and stair-step interpolation. Both higher and lower rolling averages were demonstrated by including the auto-sampler data. Ideally, a variable sampling interval would supplement fixed interval sampling, instead of only constant sampling time interval. With this approach, additional sampling would occur during and after rainfall events, and during or shortly after atrazine applications.

2. Role of Autosamplers: If variable sampling is cost prohibitive, more extensive use of auto-samplers may be the best method for obtaining more complete coverage of the peak atrazine events. In contrast to the field sampling that collects a water sample at a single point in time, the auto-samplers employed in this study provide a continuous "sipping" sample during a 6 or 8 hour period. This process of compositing samples affects peak estimation. As an example, Leu et al. (2005) intensively sampled watershed effluent for atrazine in three small catchments that were approximately 300 to 1,000 acres in size. Two auto-samplers were placed in each catchment, one which sampled approximately every half hour and another which sampled on 7 to 15 minute intervals during rainfall events. From their data, one can estimate the impact of creating a 6 or 8 hour composite sample during either the rising or falling limb of the chemograph. One such analysis by a Panel member found that an 8 hour composite sample was approximately 66% of the peak concentration. CASM is based on daily atrazine levels. A conservative approach would be to use the daily maximum, something that both sampling methods are missing. By compositing samples over 6 or 8 hours, the auto-samplers are providing an approximate average atrazine level for that period.

Systems that record a rolling average concentration measurement might be a better alternative to compositing samples for 6 to 8 hour periods. For example, a system analogous to the continuous air monitoring (CAM) systems that provide 8 and 24 hour average concentration measures, as well as quarterly and annual values, would allow greater flexibility for subsequent data analysis. Such a device could be placed in situ and used to provide an average concentration estimate for pre-defined exposure periods.

3. Concentration Applied to CASM: The above discussion raises another question: What atrazine concentration should be used for modeling? CASM_Atrazine assumes a constant concentration for each 24 hour period, but atrazine concentration within "vulnerable" Midwestern U.S. streams may vary greatly during any given 24 hour period, especially if a flow event occurs shortly after chemical application. If a CASM_hourly time step model existed, which could account for hourly variations in atrazine, the average daily SSI percentage could be estimated for any hourly chemograph. Whether the average daily SSI percentage from a CASM_hourly time step model would be the same as that obtained using a daily average atrazine concentration in CASM_Atrazine is not at all evident. This upscaling issue should not be overlooked when evaluating the uncertainty associated with the sampling technique.

4. Alternatives to Intensive Sampling: If more intensive sampling, such as that provided by variable sampling times or auto-samplers is not feasible, little can be done to improve the interpolation method unless additional information is incorporated into the process. For example, rainfall and changes in stream flow, particularly shortly after atrazine applications, often lead to increased atrazine levels in the streams. Developing an interpolation method that could take advantage of additional information of this type, perhaps coupled with simulated output from a model (e.g., such as the Pesticide Root Zone Model, PRZM, Carsel et al., 1998) would be both challenging and valuable. Other options include using a conservative probabilistic approach, such as stochastic models or spatial regression models that may provide better values for missing days. Another option would be to employ some form of trend/model analysis to account for the influence of rainfall, application timing, etc., using the auxiliary flow data and proximity to application timings to drive the model. An ensemble Kalman filter approach with an appropriate base model related to the depth-estimates of flow and application timing is another possibility.

5. Low-Flow and Intermittent Streams: As illustrated by the Agency, the low-flow or intermittent flow streams provide particular challenges for interpolation. Alternative sampling methods that do not require streams to be at least 5 inches deep should be considered. The use of auto samplers may prove to be useful in this setting, perhaps modified to provide estimates more applicable to rolling average concentrations, using some type of design that enables such time-weighted average concentration measurement.

6. Accounting for Uncertainty: The second part of Question 9 is focused on accounting for uncertainty in model results and perhaps additional uncertainty attributed to interpolation method. However, the Agency should place this specific aspect of uncertainty and safety factors in the context of all sources of uncertainty. Some uncertainty is associated with Brock scores as can be seen by the substantial overlap, especially between scores of two and three, the scores separating levels below and above the LOC. In addition, as George Box once stated, "all models are wrong, but some are useful" (Box and Draper, 1987); therefore, CASM_Atrazine is undoubtedly a useful model but, as has been clearly stated here, it is not an accurate model of any given system. Instead, it is a tool for evaluating the relative effects of atrazine on a system. Yet, the microcosm/mesocosm studies used to calibrate the model are quite different from any of the real systems. The studies have either constant elevated atrazine or a single pulse of increased atrazine, and water flow is relatively stable. Neither of these conditions, as has been stressed earlier, is observed in the watersheds; that is, the pattern of time exposures being observed differ from those used to calibrate the model. Generally, when moving from the laboratory to the field, increased variability in outcomes is observed, and this should be anticipated here as well. Quantifying this increased variability requires some comparisons between the model and actual field results. This is likely the largest source of variation and one that, as the Panel stressed earlier in this report, has not been fully considered.

Even if the model is "correct", further uncertainty is associated with imprecise knowledge of model parameters. Sensitivity analyses were used to attribute a measure of 2X to this source of uncertainty. Although the sensitivity analyses were used to choose 2X as the measure of uncertainty, the process of moving from the sensitivity analyses to the 2X seems to be somewhat arbitrary to some Panel members.

The 2X for example, does not include the uncertainty introduced by using 4-day grab samples to approximate a continuously changing level of atrazine. The variations in site grab data, site grab data augmented with auto-sampler data, site data filled in using PRZM, and Heidelberg comparisons all illustrate the variability that is inherent in any sampling regime. Therefore, placing additional uncertainty bounds on monitoring data to account for uncertainty in the ability of the sampling strategy to capture the magnitude and duration of atrazine exposures is appropriate. The W46 sampling regime in the Crawford data (Crawford, 2004), which is most similar to AEEMP 4-day scheme, suggests underestimation of exposure can be as much as 25-50% depending on the target concentration (99^{th} percentile of the yearly distribution) and the specific stream. This is similar to the uncertainty estimated in the 4 day auto-sampler augmented to the 4-day regime. The Panel suggested that this seems an avenue worth pursuing in trying to determine an appropriate uncertainty factor to apply based on sampling frequency.

Because the peaks in atrazine levels following rainfall events are generally short in duration, under sampling generally leads to low-biased estimates of upper percentiles and other concentration statistics most affected by less frequent, high-concentration conditions. An effort has been made to provide a conservative analysis. However, it may be that the effect of missing the peak in atrazine concentrations is propagated through CASM_Atrazine and the SSI resulting in an underestimate of atrazine's effect on the stream systems. Efforts to account for this are made during the calibration process, but it is not evident that this was fully successful, pointing to the importance of the sensitivity analyses.

Question 10:

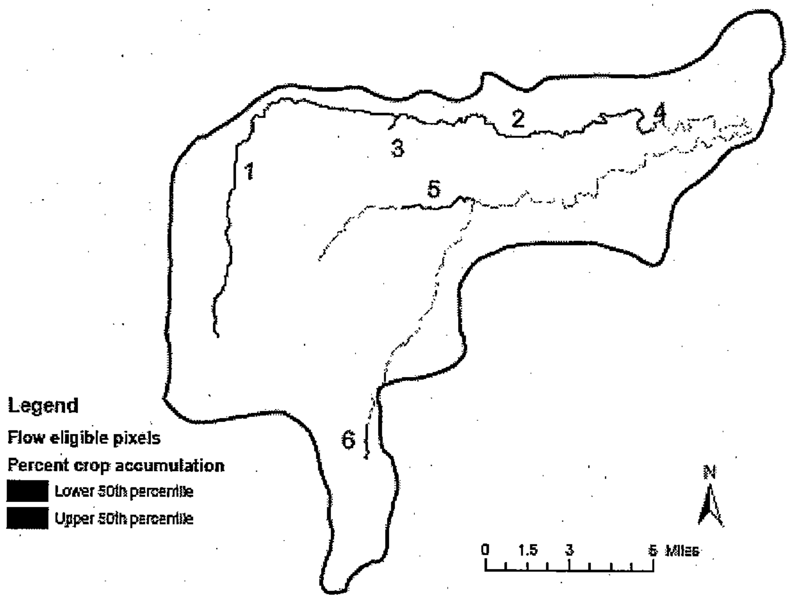
While the monitoring study was based on a watershed vulnerability assessment, the ultimate value is in identifying water bodies where atrazine concentrations exceed the LOC. One approach is to use the updated version of the National Hydrography Database (NHDPlus) and apply the criteria used to select the monitoring locations to identify streams that appear to have the potential to exceed the LOC.

- Please comment on the strengths and weaknesses of the Agency's proposed approach for identifying streams within watersheds that exceeded the LOC.
- In what ways can the preliminary approach be improved?
- Please recommend alternative approaches, if any that may be better suited to apply the watershed-based assessment to streams?
-

Panel Response

1. General Observations: Based on the study design, unbiased estimates of the number and percentage of watersheds with at least one stream segment exceeding the LOC and the precision of those estimates can be obtained. To identify water bodies where atrazine concentrations exceed the LOC, a shift to a model-based (as opposed to a design-based) approach is appropriate. A first step to identifying stream segments within the HUC-10 watersheds that exceed the LOC for atrazine would be to map out the stream segments that met the initial selection criteria for monitoring site locations and identify those sites that exceeded the LOC. This reasoning should identify extents of stream segments that potentially exceed the LOC.

2. Existing Monitoring Site Selection Criteria to Identify Streams Exceeding the LOC: The primary benefit of the approach stated above is that it would be consistent with the approach used to identify the watersheds for the monitoring study. While a clear rationale existed for the selection of the minimum and maximum areas to be monitored, it was unclear the value of and/or implications of the flow accumulation criteria. The flow accumulation computations for urban and cropped areas may be unnecessarily complicated, and their impact on stream segment selection is unclear. Criteria based on the area of the sub-watershed with urban (e.g., <10% of watershed area) and row-crop land covers (e.g., >30%) would seem sufficient, but the effect of area-based criteria on stream segment selection should be compared to the results of the existing flow accumulation criteria.



Name	Segment	Upstream Drainage Area (mi^2)	Downstream Drainage Area (mi^2)	Downstream Percent crop accumulation	Length (mi)
Youngs Creek	1	9.9	48.6	44.2	15.1
Youngs Creek	2	60.8	87.4	44.0	12.9
Youngs Creek	3	10.7	12.2	47.7	0.7
Youngs Creek	4	87.7	87.7	44.0	0.03
Youngs Creek	5	25.7	30.2	46.5	3.2
Youngs Creek	6	9.1	10.3	44.9	1.3

Figure 1. Extent of stream segments in the MO-02 HUC that met the sample selection criteria (from Harbourt et al, 2004).

The example of this approach provided in the White Paper as indicated by a Panel member provides erroneous results. The Long Branch watershed example identifies six segments meeting the existing criteria (Figure 1). Using the existing monitoring site selection, a significant portion of the Young's Creek sub-watershed is omitted, as well as the stream segment above segment 5. Given the similarity in land-use and soils throughout the watershed, the entire watershed, except the reach immediately below the city of Centralia, MO, would likely exceed the LOC. An example is given below based on USDA-ARS data collected as part of a multi-scale monitoring project in the Long Branch watershed (Figure 2). The data in Figure 2 show peak running averages beginning on April 14, 2005 for each of the four sites. Data for Goodwater Creek (MO-02) were linearly interpolated, while data from the other sites were not interpolated, but merely averages of the raw data. This sampling regime (grab samples during base flow and automated samplers during runoff) could be recommended for use in future monitoring studies. From this example, a Panel member provided three conclusions: 1) existing monitoring selection criteria are inadequate for assigning stream segments that will exceed the LOC *within* HUC 10 watersheds; 2) the multi-scale monitoring data within the Long Branch HUC 10 watershed shows that the entire watershed should be considered to exceed the LOC; and 3) the statistically designed atrazine ecological exposure monitoring program (AEEMP) supports inferences about the HUC 10 watershed based on results of the monitored sub-watershed. The Panel recognized that this example only entails one HUC 10 watershed for one year, but, it does illustrate that the existing monitoring site selection is insufficient to accurately choose those stream segments within a watershed that may exceed the LOC.

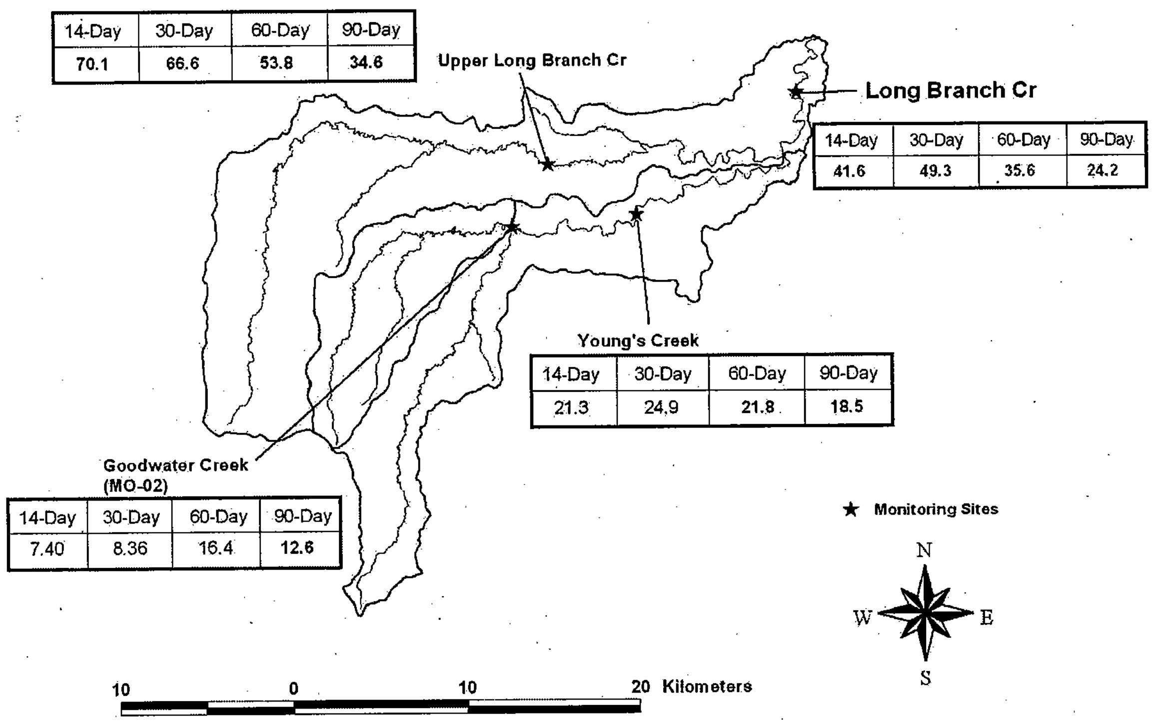


Figure 2. Multi-scale monitoring of the MO-02 HUC (Long Branch Creek). Average 2005 atrazine concentrations for time intervals used to trigger the LOC evaluation. Red numbers indicate exceedances of the running average criteria.

3. Use of Existing and Improved Soil and Hydrologic Databases: While the AEEMP study was based on a watershed vulnerability assessment, the ultimate purpose is to identify water bodies where atrazine concentrations exceed the LOC. The Panel encouraged the approaches discussed earlier (Evaluation of Other Soil- and Hydrology-Related Parameters) and those discussed in Agency presentations. The use of soil and hydrologic databases to identify vulnerability to atrazine contamination is crucial to ensuring that streams in agricultural watersheds are properly identified and ultimately protected from unacceptable degradation in water quality and ecosystem function. The Soil Survey Geographic (SSURGO) Database and NHDPlus databases will allow more soil and hydrology related parameters to be characterized which, while recognized, were not necessarily adequately weighted in the current assessment.

The AEEMP has identified some of the key soil characteristics associated with watersheds exceeding the LOC (e.g., MO-01 and MO-02), such as clay pans and possibly other restrictive soil layers. Since vulnerability is a combination of the physical setting and the land use, the best approach would be to build on the idea that vulnerable watersheds have specific soil characteristics in combination with some minimum atrazine use criteria (or minimum corn and sorghum acreage). Assuming that adequate herbicide usage (see comments below) or crop-specific land use data are available to identify those watersheds with significant atrazine usage, then the challenge is to identify the key soil characteristics associated with watersheds known to have exceeded the LOC in the AEEMP. In this regard, the SSURGO soil database offers the best approach for identifying the needed soil characteristics, and it could be used to extrapolate to the larger population of watersheds or stream segments exceeding the LOC (see response to question 11).

Using a GIS-based approach, the first-tier watershed assessment of those soil characteristics associated with vulnerable sites should include the following: 1) presence, type and extent of restrictive soil layers; and 2) extent of soil hydrologic groups C and D. A second-tier of assessment should employ quantitative criteria such as, but not limited to the following: 1) minimum depth to restrictive layers; and 2) saturated hydraulic conductivity (K_{sat}) of the restrictive layer. An additional level of sophistication to the evaluation of vulnerable watersheds would be to employ the use of risk assessment index models, which integrate a wide range of SSURGO soil properties with the chemical properties and environmental fate of the contaminant in question. Currently, four Midwestern states are pursuing the application of such a risk assessment index model to determine relative risks of pesticide contamination in surface and ground waters (Shea and Milner, 2006). The Panel is encouraged that this approach or a similar course of action can be used and that it should provide a wealth of data. In combination with other geospatial data (e.g., pesticide use), the SSURGO database would appear to be most appropriate for identifying relative risks between and within watersheds.

NHDPlus is an integrated suite of application-ready geospatial data sets that incorporate many of the best features of the National Hydrography Dataset (NHD), the National Elevation Dataset (NED), the National Land Cover Dataset (NLCD), and the Watershed Boundary Dataset (WBD) http://www.horizon-systems.com/nhdplus. Strengths of NHDPlus include the following: 1) greatly improved 1:100k National Hydrography Dataset (NHD); 2) a set of value added attributes to enhance stream network navigation, analysis and display; 3) an elevation-based catchment for each flow line in the stream network; 4) catchment characteristics; 5) headwater node areas; 6) cumulative drainage area characteristics; 7) flow direction, flow accumulation and elevation grids; 8) flow line minimum/maximum elevations and slopes; and 9) flow volume and velocity estimates for each flow line in the stream network. The NHDPlus dataset would provide a set of hydrologic characteristics useful for identifying watersheds or stream segments exceeding the LOC in a manner analogous to that of the soil characteristics. Flow characteristics indicative of vulnerable watersheds could be identified and used in addition to the soil characteristics included in the first-tier assessment discussed above. An additional hydrologic characteristic useful for a first-tier assessment would be the computation of a Runoff Propensity Index (RPI) [RPI = log(90th percentile Q/10th percentile Q), where Q = stream discharge)] (Blanchard and Lerch, 2000), at locations for which long-term discharge data exist (i.e., at least 10 years). Blanchard and Lerch (2000) showed that watersheds with a RPI > 2 were indicative of watersheds with high vulnerability to surface transport of herbicides.

4. Applicability of WARP Model: The original version of WARP applied by EPA for AEEMP design was a useful tool for predicting long-term average 95th percentile atrazine concentrations as part of the watershed selection criteria, but it needs to be refined to better evaluate the larger population of vulnerable stream segments across the full range of watershed sizes (including small sub watersheds). One of the main reasons for this is that the independent variables and predicted concentrations (annual 95th percentile) included in the WARP regression model, as applied, were developed on a broader set of watersheds, mostly larger than the AEEMP watersheds, which did not necessarily include the most vulnerable watersheds (the intended target for the AEEMP). Another weakness in applying the original WARP model for the purpose of identifying stream reaches exceeding the LOC is that it is a regression model developed to estimate long-term annual atrazine concentration statistics; thus, it was not designed for the level of prediction resolution and accuracy needed to identify stream segments exceeding the LOC *within* HUC 10 watersheds nor can it reliably predict annual changes caused by variations in weather and herbicide usage. In particular, WARP and other modeling approaches, indeed all possible approaches, rely on accurate herbicide usage data for their success. Such use data are typically of uncertain accuracy, especially for small watersheds, and may be subject to significant year-to-year changes in some sub-watersheds.

Although these obstacles need attention and improvement, the Agency requires an estimate of which and how many stream miles have a stated probability of exceeding the LOC and, with modifications, the WARP approach appears to be the most viable approach. To make WARP a more useful tool for estimating stream miles or watersheds exceeding the LOC, a new set of WARP models should be developed for this specific problem, one for each rolling average period (instead of annual concentration percentiles). For this analysis, we suggest restating the LOC in terms of specific rolling average atrazine concentrations, rather than SSI. This will have little impact on how chemographs are interpreted in relation to the LOC (because of the high correlation between the rolling averages and the SSI), will be much more transparent, and will be more directly related to concentration statistics that are measured or estimated.

The original and future goal is to estimate the number of stream miles, or potentially watersheds, that exceed the LOC, with a corresponding estimate of reliability. To get to stream miles, several steps were discussed by the Panel that will be needed to update and improve the WARP model, all of which are feasible using data that are already or nearly available, including the following:

1) update hydrologic framework to NHDPlus and drop the analytical linkage to the original HUCs. The HUCs were a useful design framework, but an unnecessary constraint on future analyses;

2) update all possible estimates of causal factors using improved data sources, including the best possible estimates of use during sampling years for model development sites. Independent predictor variables should include updated atrazine usage data and relevant parameters from SSURGO and/or NHDPlus. Use of a common hydrographic dataset, as discussed above, will improve characterization of the sub-watersheds being modeled by WARP. It should also allow for an estimate of corn/sorghum crop area within a sub-watershed instead of using the total (HUC 10) watershed area;

3) add other existing monitoring sites to the database, as possible. It is important to include the representative range of scales needed to represent the entire stream miles;

4) as part of this effort to update the WARP model to address the atrazine assessment problem, the scale of analysis should be expanded to include the entire Corn Belt.

5. Herbicide Usage Data Issues: If the intent is to identify specific stream segments within HUC 10/11 watersheds, then better herbicide usage data will be needed than is currently available. In small sub-watersheds, farmer surveys may be needed to augment existing state or county data. Another approach is to acquire herbicide sales data (which the registrant could provide) and use it to estimate usage. The State of Iowa is currently using this approach, and they have a well defined procedure for converting sales data to usage that could be used elsewhere. With the approach used for selecting monitoring sites, it was unclear what the land use, and therefore, herbicide usage actually was for the monitored sub-watersheds. The utility of the AEEMP data will be enhanced considerably if estimates of the corresponding sub-watershed atrazine use data can be compiled for the study years. One possibility mentioned during the Panel meeting was that remote sensing methods allow accurate identification of fields cropped to corn, which would allow an accurate estimate of the corn acreage within each monitored sub-watershed. The ability to update atrazine usage data is crucial at the sub-watershed level and incorporation into the criteria for identifying vulnerable sub-watersheds will strengthen the assessment particularly if local usages can be better estimated.

Question 11:

In order to identify areas beyond the 40 study sites where higher atrazine exposures are likely to occur, the Agency must determine whether the watersheds that exceeded the LOC in multiple years are randomly distributed within the 1,172 vulnerable watersheds or represent a unique subset of conditions. If the latter and the conditions can be identified, monitoring could be focused only in watersheds where those conditions exist. The Agency has proposed evaluating WARP parameters and other sub-watershed soil and hydrologic properties to determine the extent to which the monitoring results can be used to identify other water bodies exceeding the LOC.

- To what extent can WARP be used to identify other watersheds of concern? Given the influence of atrazine use on vulnerability and exposure, please comment on whether the extrapolation should be limited to the original 1,172 watersheds or include a broader atrazine use area?

Panel Response

1. General Observations: The WARP model developed by USGS (Larson et al., 2004) is a multiple regression model with its "most important explanatory variable" associated with "atrazine use intensity" (amount of atrazine used in a watershed divided by the area of the watershed). WARP predictions are primarily driven by the pesticide use data so having the most accurate atrazine use data (both spatial and temporal) is important. In WARP, atrazine use is defined as the average mass of atrazine applied to a unit area of watershed land on an annual basis.

The Panel recognized additional costs will be necessary to extend sampling beyond the original 1,172 watersheds. However, it would be valuable to assess a broader atrazine use area, via GIS, with those HUC 10 watersheds that were not included in the original 1,172 vulnerable watersheds as to the presence of restrictive layers and hydrologic soil groups C and D and compute runoff propensity indices [RPI = log (90th percentile Q/ 10th percentile Q); Q = stream discharge; Blanchard and Lerch (2000)]. If other watersheds are not identified, then there would be even greater confidence in the original 1,172 selected watersheds. If other watersheds did meet these soil/ hydrologic criteria, then they could be included in future monitoring efforts. This recommendation is related to the recommendation made in the response to Question 10 that the analysis should be expanded to the entire Corn Belt.

2. Revision of WARP Model: As noted above, the Panel recommended the Agency consider revising the WARP model coefficients and parameters by re-fitting the step-wise regressions using the most current and accurate data. This approach will provide insight by examining other potentially vulnerable watersheds and better meet the Agency's goal of identifying stream reaches/watersheds that might exceed the LOC. Designing the regression analysis may require selecting locations with specific characteristics for model validation and therefore targeted sampling may be needed. Temporal changes in atrazine use (application rates, area treated) should also be considered in this analysis. Recent increases in land area for corn production associated with bioenergy and other economic factors will influence future changes in land use. Also, timing of pesticide applications may vary if marked changes in precipitation from changing climate are observed. As noted above, remote sensing technologies can also help fine-tune corn harvest data and provide information on spatial and temporal changes in other environmental variables.

3. Refinements to Geographic Data: The application of geographic information systems with environmental and natural resources geospatial data is a scientifically-valid exercise to understand the spatial dimension of atrazine use in stream environments. As stressed above, the Panel suggested the Agency use the most accurate and current herbicide application data (especially relative to atrazine use on a watershed area basis). Based on the subwatershed to watershed scales currently being studied, past efforts to obtain and utilize detailed county soil survey data and other large mapping scale geospatial layers are to be commended. The use of risk assessment index models based on SSURGO data and the use of improved herbicide usage data is a potential application.

The Panel suggested that care be exercised with regard to scale effects and geospatial data resolution in conducting this analysis. Recommendations for handling scale effects are discussed by Gotway and Young (2002) and others. The Panel also had trouble with the meaning of the term "vulnerability" often used by the Agency. It is recommended that the term be explicitly defined since the various possible routes of transport of atrazine from fields include surface runoff, leaching to groundwater and subsequent return to a stream as base flow, and facilitated subsurface transport associated with tile drainage. EPA could evaluate additional methods and sources such as the work recently described by Sugg (2007) and others to identify accurate geospatial data for the extent of tile drainage. In some cases, the estimation of land area with tile drainage based on dual hydrologic soil groups may be inaccurate as a result of regional soil data variation with time, local bias and interpreting soil properties and changes in classifying hydrologic soil groups.

In addition to using diagnostic soil horizon information ("argillic soils" or soils with argillic horizons), the Agency should evaluate other methods to identify restrictive soil layers based on subsurface soil characteristics such as saturated hydraulic conductivity data and classes. Where available, information on soil restrictive layers can be derived from specific soil classification terms such as "Fragiudalfs," a soil grouping that indicates the presence of a "fragipan" or diagnostic subsurface horizon that occurs in some landscapes and may cause a "perched" water table associated with lateral subsurface flow. In other regions, an unrestrictive horizon called a "hard layer" may form in soils that restrict downward water movement. If this does occur, the Panel suggested that the Agency consult with USDA-ARS or NRCS soil scientists to assist in identifying soil layers in particular soil series that influence water movement. Consultation by Agency staff with area soil scientists should assist with identifying watersheds that contain soil series possessing restrictive layers.

Terrain data may be a useful source of geospatial data when interpreting site specific monitoring data with grid or pixel size varying from 1 km to 30m to 10 m to even larger scales (e.g., less than 1 meter with recently available LIDAR data). Some landscape scale or geomorphologic properties and hydrologic or flow characteristics (e.g., NHDPlus) can also be determined using digital elevation models (DEMs) which contain x, y (locational) and z (elevation) data to display and visualize land surface terrain. For example, a simple ratio of maximum to minimum elevation within a watershed serves as an index of watershed variability when compared to other watersheds (Wilson and Gallant, 2000; Maune, 2001). Improved modeling capabilities that relate rainfall and runoff at the field scale should be an objective for the Agency. Hydrologic models can also link with landscape scale processes using DEMs for various models such as SWAT (Soil Water Assessment Tool).

4. Additional Issues: Based on the Agency presentations, the stream segment is the sampling unit. The sampling site associated with the stream segment represents a point selection within the watershed. The Panel was concerned about the representativeness of subwatersheds to watersheds and believed that care should be taken in generalizing WARP to subwatersheds, as discussed in more detail in the Panel response to Question 10. In conjunction with their efforts to determine site specific characteristics associated with vulnerable watersheds, the Agency should carefully evaluate the PRZM runs conducted for the 40 monitoring sites since their model inputs should represent field site conditions. Maps of drought potential or soil moisture and climate may provide additional information on runoff potential. Efforts to convert edge-of-field estimates to stream concentrations are interesting and may offer further insights. Additional study of the measured chemographs and hydrographs for the 40 sites may also augment site specific data. Where appropriate, the Agency could work with area soil scientists to assist during field site visits with selection of monitoring locations. Through the process, both parties will share experiences to help understand site conditions within the watershed. Examination of current aerial photography, 3D terrain models and other remotely-sensed imagery can also provide valuable information. The effects of conservation practices (Best Management Practices and potential land use changes in the Conservation Reserve Program) and agricultural management (e.g., corn stover or crop residue removal) should also be considered when evaluating site specific monitoring data and atrazine chemographs.

REFERENCES

Anderson J (1995) Soil organisms as engineers: microsite modulation of macroscale processes. In: Jones CG, Lawton JH (eds) Linking species and ecosystems. Chapman and Hall, New York, p 94-106

Bengtsson J, Engelhardt K, Giller P, Hobbie S, Lawrence D,Levine J, Vilà M, Wolters V (2002) Slippin' and slidin' between the scales: the scaling components of biodiversity-ecosystem functioning relations. In: Loreau M, Naeem S, Inchausti P (eds) Biodiversity and ecosystem functioning: synthesis and perspectives. Oxford University Press, Oxford, p 209-220.

Blanchard, P. E., and R.N. Lerch. 2000. Watershed vulnerability to losses of agricultural chemicals: Interactions of chemistry, hydrology, and land-use. Environmental Science and Technology 34:3315.

Box, G. E. P., and N. R. Draper. 1987. Empirical Model-Building and Response Surfaces, John Wiley and Sons, NY, NY.

Brock, T.C.M., J. Lahr, P.J. van den Brink, 2000. Ecological risks of pesticides in freshwater ecosystems. Part 1: Herbicides. Wageningen, Alterra, Green World Research. Alterra-Rapport 088. 124 pp.

Bulling, M.T., C. L. White, D. Raffaelli, and G. J. Pierce. 2006. Using model systems to address the biodiversity–ecosystem functioning process. Marine Ecology Progress Series 311: 295–309.

Carsel, R.F., J.C. Imhoff, P.R. Hummel, J.M. Cheplick, and A.S. Donigian, Jr. 1998. PRZM-3, A Model for Predicting Pesticide and Nitrogen Fate in the Crop Root and Unsaturated Soil Zones: Users Manual for Release 3.0, National Exposure Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia. Available at http://www.epa.gov/ceampubl/gwater/przm3/przm3122.htm.

Crawford, C.G. 2004. Sampling strategies for estimating acute and chronic exposures of pesticides in streams. Journal of the American Water Resources Association (JAWRA) 40(2):485-502.

Cukier, R.I, H.B. Levine, and K.E. Shuler. 1978. Nonlinear sensitivity analysis of multiparameter model systems. Journal of Computational Physics 26:1-42.

Gotway, C.A., and L.J. Young. 2002. Combining Incompatible Spatial Data. Journal of the American Statistical Association 97: 632-648.

Hampton, M., G. Burnett, L. S. Carver, C. M. Harbourt, P. Hendley, E. A. Johnston, S. Perez, N. J. Snyder, and J. R. Trask. 2007. 2007 Syngenta Interim Report - 2004-2006 Data Overview - Atrazine ecological exposure flowing water chemical monitoring study in vulnerable watersheds. Syngenta Report Number T00150803.

Harbourt, C.M., J.R. Trask, M.K. Matella, M.H. Ball, and J.M. Cheplick. 2004. Sampling Site Selection: Atrazine Ecological Exposure Flowing Water Chemical Monitoring Study in

Vulnerable Watersheds - Youngs Creek, MO (MO-02). Prepared by Waterborne Environmental, Inc., Leesburg, VA for Syngenta Crop Protection, Inc., Greensboro, NC. Syngenta Number T001508-03, volume 22.

Huston MA (1994) Biological diversity. The coexistence of species on changing landscapes. Cambridge University Press, Cambridge

Huston, M. A. 1979. A general hypothesis of species diversity. American Naturalist 113:81-101.

Larson, SJ; Crawford, CG; Gilliom, RJ. 2004. Development and Application of Watershed Regressions for Pesticides (WARP) for Estimating Atrazine Concentration Distributions in Streams. Water Resources Investigations Report. United States Geological Survey. Water Resource. Invest. Res. Report 4047.

Leu, C., H. Singer, S. R. Muller, R. P. Schwarzenbach, and C. Stamm. 2005. Comparison of atrazine losses in three small headwater catchments. Journal of Environmental Quality 34:1873-1882.

Maune, D.F. 2001. Digital Elevation Model Technologies and Applications: The DEM Users Manual, 1st Edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 539 pp.

Meyer, JL. DL. Strayer, B.B. Wallace, S.L. Eggert, G.S. Helfman, and N.E. Leonard. 2007. The contribution of headwater streams to biodiversity in river networks. American Water Resources Association 43: 86-103.

National Hydrography Dataset – Plus (NHDPlus). Accessed Jan. 23, 2008. http://www.horizon-systems.com/nhdplus/

Novak, J.M., D.W. Watts, K.C. Stone, M.H. Johnson, and P.G. Hunt. 1998. Pesticide and metabolites in the shallow groundwater of an eastern Coastal Plain watershed. Trans. ASAE 41:1383-1390.

Novak, J.M., D.W. Watts, K.C. Stone, and M.H. Johnson. 2001. Seasonal occurrence and export of five herbicides from a North Carolina Coastal Plain watershed. Trans. ASAE 44:1201-1206.

O'Neill, R.V., S.M. Bartell, and R.H. Gardner. 1983. Patterns of toxicological effects in ecosystems: a modeling approach. Environmental Toxicology and Chemistry 2:451-461.

O'Neill, R.V., R.H. Gardner, L.W. Barnthouse, G.W. Suter, S.G. Hildebrand, and C.W. Gehrs. 1982. Ecosystem risk analysis: a new methodology. Environmental Toxicology and Chemistry 1:167–177.

Petchey OL, Morin PJ, Hulot FD, Loreau M, McGrady-Steed J, Naeem S (2002b) Contributions of aquatic model systems to our understanding of biodiversity and ecosystem functioning. In: Loreau M, Naeem S, Inchausti P (eds) Biodiversity and ecosystem functioning: synthesis and perspectives. Oxford University Press, Oxford, p 127-138

Petersen JE, Hastings A (2001) Dimensional approaches to scaling experimental ecosystems: designing mousetraps to catch elephants. Am Nat 157:324-333.

Shea, P. J., and Milner, M. 2006. Targeting watershed vulnerability and behaviors leading to adoption of conservation management practices. USDA-CSREES- Integrated Research, Education, and Extension Competitive Grants Program.

Sugg. Z. 2007. Assessing U.S. farm drainage: Can GIS lead to better estimates of subsurface drainage extent. World Resource Institute, Washington, D.C. Available on the internet at: **http://pdf.wri.org/assessing_farm_drainage.pdf** Verified on Dec. 14, 2007.

Tarantola, S., D. Gatelli, and T.A. Mara. 2006. Random balance designs for the estimation of first order global sensitivity indices. Reliability Engineering and System Safety 91:717-727.

Tilman D, Knops J, Wedin D, Reich P (2002) Plant diversity and composition: effects on productivity and nutrient dynamics of experimental grasslands. In: Loreau M, Naeem S, Inchausti P (eds) Biodiversity and ecosystem functioning: synthesis and perspectives. Oxford University Press, Oxford, p 21-35

Volz, D.C., S.M. Bartell, S.K. Nair, and P. Hendley. 2007. Atrazine: Modeling the potential for atrazine-induced changes in Midwestern stream ecosystems using the Comprehensive Aquatic Systems Model (CASM). Final Report. Syngenta Crop Protection and E2 Consulting Engineers, Inc. 152 pp.

Wilson, J.P. and J.C. Gallant (eds.) 2000. Terrain Analysis – Principles and Applications. John Wiley and Sons, Inc. New York. 479 pp.

Xu, C., G. Z. Gertner, and R. M. Scheller. Uncertainty in forest landscape response to global climatic change. Global Change Biology (*in review*).

Xu, C., and G.Z. Gertner. 2007a. Extending a global sensitivity analysis technique to models with correlated parameters. Computational Statistics and Data Analysis 51: 5579-5590.

Xu, C., and G.Z. Gertner. 2007b. A general first-order global sensitivity analysis method. Reliability Engineering and System Safety (*In press*).

Zhou, Y.H., D. McLaughlin, and D. Entekhabi. 2006. Assessing the performance of the ensemble Kalman filter for land surface data assimilation. Monthly Weather Review 134 (8), 2128-2142.