UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

- Quality Review Draft –
February 24, 2006

EPA-SAB-06-xxx

The Honorable Stephen L. Johnson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Review of Agency *Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models* and *Models Knowledge Base* by the Regulatory Environmental Modeling Guidance Review Panel of the EPA Science Advisory Board

Dear Administrator Johnson:

The EPA Regulatory Environmental Modeling (REM) Guidance Review Panel of the Science Advisory Board has completed its review of the Agency's Council on Regulatory Environmental Models (CREM) *Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models,* dated November, 2003 (also referred to as the *Draft Guidance*), and the *Models Knowledge Base* (*MKB*), an online database of environmental models.

The Panel commends the Agency's REM initiative, which provides a much needed vision for modeling across all EPA offices. The *Draft Guidance* in particular provides a comprehensive overview of modeling principles and best practices. The Panel notes that the Agency has been very responsive to previous SAB advice on environmental modeling, and recommends that special recognition be accorded to Agency REM participants for their leadership. However, the Panel is concerned that the REM vision is not matched by a commensurate, and steady, allocation of resources on the part of the Agency. It is therefore recommended that the Agency provide a meaningful commitment of resources to the REM initiative.

The Panel also commends the Agency for recognizing the need for and beginning development on the *Models Knowledge Base.* This type of resource has been needed for some time and even in its draft form, the *MKB* provides an easily accessible resource for the modeling community that, if maintained and used, will significantly improve the development and application of models both internal and external to the Agency.

The *Draft Guidance*, as it is written, is comprehensible to relatively limited constituencies, i.e. those who develop and use models. Yet, it will be read and used by a wide variety of audiences including analysts, managers at various levels, decision-makers, and other stakeholders who come from Federal, State, and private sectors. Accordingly the Panel recommends that the Agency clarify carefully the use of the *Guidance Document* for a variety of audiences, describing or suggesting how it can be used beneficially by different constituencies in a modeling project.

The Panel has made note of the importance of explicitly including the specifics of the problem posed (Problem Specification), and for which a model is to be applied, in the *Draft Guidance*. Further, the Panel believes that all stakeholders must be recognized and their central role in the public policy process be understood, thus the Problem Specification should be agreed upon by all stakeholders and used to guide model conceptual development, complexity, data needs, and interpretation of output.

As noted in the *Draft Guidance* the evaluation of uncertainty in the application of models is an important element in both understanding a system and in presenting results to decision-makers, a point with which the Panel concurs. Indeed the use of Quantitative Uncertainty Assessment (QUA) methods is a desirable, and often necessary component of modeling. However, experience suggests that the use of increasingly complex QUA techniques without an equally sophisticated framework for decision-making and communication may only increase management challenges. Accordingly the Panel recommends that the REM *Draft Guidance* strongly advise modelers to begin model development only after an awareness of how the decision-maker plans to use the information on uncertainty exists. And while the Panel agrees with the Agency on the importance of uncertainty analysis, we find that the *Draft Guidance* is deficient in articulating a more tangible set of alternatives for assessing model sensitivity and uncertainty. References cited in the *Draft Guidance* provide an array of applicable methods to address model uncertainty, however the document as a whole does not provide sufficient discussion, context, and recommendations necessary to provide a model user/decision-maker with "practicable" information relating to appropriate uncertainty analysis methods and how to convey the results of such analyses.

The Panel finds that the use of modeling terminology is often inconsistent with Agency past uses, or usage common in the modeling community. It is recommended that these inconsistencies be recognized through developing and using a common reference, the Glossary, in which these and other terms are carefully defined.

The Panel finds that there is a need to gather, and in many cases to develop, additional information to be included in the *Models Knowledge Base*, including the model framework, evaluation, and limitations. The Panel views an important purpose of the *MKB* as providing an incentive for model developers and purveyors to conduct and openly communicate their efforts in model evaluation. From this perspective, the Panel recommends some additional pieces of information that should be elicited and reported, including:

1) Documented examples of peer review for the model, including reviews conducted by the EPA, other agencies or panels, and papers presented in the peer reviewed literature. Key limitations and needs for improvement that are identified in these evaluations should be reported.

2) Provision of a mechanism that actively solicits feedback from the user community regarding application experience and model performance, both inside and outside the Agency.

In summary, the SAB finds that the *Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models* is an important document, and the *Models Knowledge Base* an important tool that will guide the Agency and others in developing and using models for environmental purposes. In the Panel's judgment it is essential that these efforts be revised and updated regularly in order for their full value to the Agency to be realized. The Panel stands ready to provide additional advice and review on this effort as it continues to unfold.

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Sincerely,

Dr. M. Granger Morgan	Dr. Thomas L. Theis
Chair	Chair
Science Advisory Board	SAB Chair, REM Guidance Review Panel
	Science Advisory Board

NOTICE

U.S. Environmental Protection Agency
Science Advisory Board
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EXECUTIVE SUMMARY

The Regulatory Environmental Modeling (REM) Panel of the SAB has reviewed the Agency's *Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models*, dated November, 2003 (referred hereafter as the Draft Guidance), and the Agency's *Models Knowledge Base* (referred to as the MKB). Major points of consensus are summarized below.[1]

The Panel commends the Agency's REM initiative, which provides a much needed vision for modeling across all EPA offices. The Draft Guidance in particular provides a comprehensive overview of modeling principles and best practices. The Panel notes that the Agency has been very responsive to previous SAB advice on environmental modeling, and recommends that special recognition be accorded to Agency REM participants for their leadership. The Panel believes that the Regulatory Environmental Models (REM) program at EPA will provide leadership and guidance for improving the quality of model development, evaluation, and application in the use of environmental models for decision support. As a part of this program, the MKB will provide a web-based database of information on selected models, including key operational and scientific features, model downloads, guidance for use, and examples of model applications provided by model developers. Nevertheless, the Panel is concerned that the REM vision is not matched by a commensurate, and steady, allocation of resources. It is therefore recommended that the Agency provide a meaningful commitment of resources to the REM initiative.

The Draft Guidance is comprehensive, and will most likely be read and used by a wide variety of audiences including model developers, analysts, managers at various levels, decision-makers, and other stakeholders who come from Federal, State, and private sectors. Yet it is written, and most comprehensible, primarily to those who develop and/or those who "use" or run

[1] This report contains the consensus views of the REM Panel on the current state of the REM program within the Agency, as presented in the Draft Guidance and the MKB documents. The report is organized by responses of the Panel to charge questions posed by the Agency. Generally speaking, each set of responses consists of statements and explanatory materials that present the Panel's point of view on a given topic, which are followed by formal recommendations, or in some cases commendations. For ease in discerning the plain meanings and actions of the Panel, these recommendations and commendations are **boldened**. Less urgent, but still important observations, suggestions, and concerns are not boldened, and/or are contained in the appendices of the report.

models to generate output. Accordingly the Panel recommends that the Agency clarify carefully the use of the Draft Guidance for a variety of audiences, describing or suggesting how it can be used beneficially by different participants in a modeling project. In the same vein, the Panel finds that the use of modeling terminology is sometimes inconsistent with Agency past uses, or usage common in the modeling community. It is recommended that these inconsistencies be recognized through developing and using a common reference, the Glossary, in which these and other terms are carefully defined. The current Glossary in the Draft Guidance should be expanded to make it as comprehensive as possible.

In the Panel's view it is important that the specifics of the problem posed be explicitly stated and agreed upon by all stakeholders, and be used to guide model conceptual development, complexity, data needs, and interpretation of output. Toward this end, the Panel suggests an alternative version of Figure 1 in the Draft Guidance in which Problem Specification is given greater emphasis (page 17 in this review). The Panel believes that this alternative figure better reflects the central role of stakeholders in the public policy process, and provides a more accurate representation of the modeling process and its iterative nature.

As noted in the Draft Guidance the evaluation of uncertainty in the application of models is an important element in both understanding a system and in presenting results to decision-makers, a point with which the Panel concurs. Indeed the use of Quantitative Uncertainty Assessment (QUA) methods is a desirable, and often necessary component of modeling, however experience suggests that the use of increasingly complex QUA techniques without an equally sophisticated framework for decision-making and communication may only increase management challenges. Accordingly the Panel recommends that the Draft Guidance strongly advise modelers to select particular QUA methods only after becoming aware of how the decision-maker plans to use the information on uncertainty. This is an important component of the Problem Specification as well.

The Panel finds that the Draft Guidance provides a generally adequate discussion of sensitivity analysis methods; however it is deficient in articulating a more tangible set of alternatives for assessing model uncertainty, and a clearer distinction between sensitivity and uncertainty analysis. While references cited provide an array of applicable methods to address model uncertainty, the Draft Guidance does not provide sufficient discussion, context, and recommendations necessary to provide a model user/decision-maker with "practicable" information relating to appropriate uncertainty analysis methods and how to convey the results of such analyses. In addition, recommendations for uncertainty analysis could identify focusing resources on those processes to which the model state variables are most sensitive *and* are less certain in terms of their formulation and/or parameterization. The topic of propagation of uncertainty in modeling frameworks relying upon linked models, is not addressed in the Draft Guidance, and warrants specific discussion. The Panel also recommends that both the Draft Guidance and the MKB provide more practicable information through inclusion of "case study" examples of where and how EPA is currently incorporating QUA in environmental models as an integral component of decision-making.

The Panel commends the Agency for recognizing the need for and beginning development on the MKB. This type of resource has been needed for some time and even in its draft form, it provides an easily accessible resource for the modeling community that, if maintained and used, will significantly improve the development and application of models both internal and external to the Agency. In its review of the MKB, the Panel arrived at several suggestions for modifying the data entry sheet that are given in our response to Charge Question 5. Perhaps the most important recommendation is the need to clarify and in some cases gather additional information on models including their framework (which in the Panel's opinion needs to be redefined), evaluation, and limitations. The Model Evaluation section of the Model Science MKB information page considers many of the key issues needed to evaluate the scientific rigor behind the underlying model development and previous applications, and addresses many of the elements of good modeling practice that are emphasized in the Draft Guidance. Indeed, the Panel views an important purpose of the MKB as providing an incentive for model developers and purveyors to conduct and openly communicate their efforts in model evaluation. From this perspective, the Panel recommends some additional pieces of information that should be elicited and reported, including:

1) Documented examples of peer review for the model, including reviews conducted by the EPA, other agencies or panels, and papers presented in the peer reviewed literature. Key limitations and needs for improvement that were identified in these evaluations should be reported;

2) Benchmarking studies in which the model's predictions and/or accuracy were compared with other models;

3) Provision of a mechanism that actively solicits feedback from the user community regarding application experience and model performance, both inside and outside the agency, beyond voluntary e-mails to designated contacts for individual models; and

4) Information on revision tracking, which should be incorporated into the MKB.

The Panel also recommends that the Agency follow its own standard QA/QC program procedures for ensuring quality of all of the underlying information in the MKB system. A meaningful commitment to QA/QC is necessary to ensure the quality of information in the MKB, without which it is doubtful the MKB will achieve its potential value and utility. This QA/QC function will require the allocation of meaningful resources on the part of the Agency.

Finally, this report contains specific experiences of Panel members (Appendix C) on the use of the MKB for three specific models that it contains. These experiences can help guide efforts by the Agency as they continue to modify the MKB in the future.

INTRODUCTION

Background Material

The Science Advisory Board has produced over 600 reports, advisories, and consultations since its inception, with approximately 20% of these devoted to the theme of environmental modeling (over 120 reports where modeling activity is fundamental to the data and information being presented to the SAB). It is clear that the SAB has made a difference on improving the state-of-the-art and science applications pertaining to encouraging sound modeling practices. The SAB has a record of continuously encouraging the Agency to move modeling practice, expectations, and modeling culture to higher levels. This report presents the latest in a series by the SAB's Regulatory Environmental Modeling (REM) Guidance Review Panel, focusing on Draft Guidance on the Development, and Application of Regulatory Environmental Models.

Perhaps the most seminal work that marked a notable milestone in the SAB's impact on the Agency's modeling efforts was the Environmental Engineering Committee's Modeling Resolution (U.S. EPA SAB 1989), in response to repeated problems observed in the development and implementation of models within the Agency that were common to modeling efforts sponsored by a variety of offices. The EEC and its Modeling Resolution Subcommittee, Chaired by Dr. Mitchell Small, believed that these common problems could be best called to the Agency's attention through a more general resolution on modeling. The basic messages from the modeling resolution resonated within the Agency were reinforced by additional modeling related studies by the SAB and its standing committees, subcommittees and panels over the next two and one-half decades. The Modeling Resolution stressed, among other things that:

1) There should be a better balance between field and laboratory data collection efforts and modeling analysis for effective environmental assessment;

2) Models for regulatory assessment and decision-making which incorporate state-of-the-art scientific understanding of the environmental processes involved should be developed and used;

3) There should be better confirmation of models with laboratory and field data;

4) Sensitivity and uncertainty analysis of environmental models and their predictions should be conducted to understand level of confidence in model predictions, as well as to identify key areas of future study;

5) An Agency-wide task group to assess and guide model use by EPA should be formed;

6) There should be an increased effort to hire and support engineers and scientists with modeling development and application skills;

7) There is a need for systematic management of model use within EPA and a careful review of emerging technologies such as personal computer-based models and expert systems; and

8) Peer Review at various levels should be coordinated to ensure proper development and application of models.

The modeling resolution identified a number of ways in which the use of models by the EPA can be improved. The SAB believed that successful implementation of the above recommendations, which would require commitment at the very top of the Agency's management, would take significant resources, would require institutional change in the Agency, would take significant time to implement, and would require the establishment of a formal institutional mechanism with the responsibility for review, oversight and coordination of model use in EPA.

1. BEST PRACTICES

<u>Charge Question 1:</u> Has EPA sufficiently and appropriately identified the best practices, such that decisions based on models developed and used in accordance with these practices may be said to be based on the best available, practicable science?

1.1. Interpretation of "Best Available and Practicable Science"

In developing and applying a model for supporting a regulatory action or decision, it is important to meet the criterion stated in question 1--"based on the *best available, practicable science*." To the Panel, this means that the model uses the best current science that is consistent with the model's intended use, whether that use is regulatory, management or scientific. The term "practicable" refers to consideration of problem specification and programmatic constraints (data quality and availability, and limitations of time and resources) in selection of model complexity (i.e., spatial, temporal, and process resolution). Thus in the context of Figure 2 of the Draft Guidance document, the Panel suggests that the location of the minimum (both in the x- and y-directions) in the uncertainty versus model complexity curve will depend on the problem specification and programmatic constraints. The Panel believes that when a model complexity is most appropriate for the problem and available data and resources, it is obtaining the minimum possible uncertainty and, hence, using the *best available, practicable science*. The Panel interprets this question as asking whether the guidance provided aids the modeler in finding that level of model complexity.

1.2. General Comments

In general, the Panel finds the REM initiative provides a common and much needed vision for modeling across all of the offices within the Agency. The draft document in

particular provides a comprehensive overview of modeling principles and best practices, in a concise manner. The Panel also finds that the Agency has been responsive to previous SAB advice on modeling practices and commends the REM participants for their leadership. The SAB looks forward to working together with the Agency to help make this guidance an excellent resource for improving the usefulness of models and modeling for decision making in the future. In particular the Panel applauds the emphasis in the document on using the peer review process to insure that a Regulatory Environmental Model is using the best available, practicable science.

The Panel encourages the document to urge that *any* regulatory modeling project include a peer review plan in its QAPP. Furthermore, the Panel suggests that the peer review plan implement *ongoing* peer review through all stages of the modeling process, not just after the model application. Such a proactive practice will assist in avoiding crucial technical errors or omissions that are difficult or impossible to rectify after the project is over. Also, the Panel favors an open modeling process for Regulatory Environmental Models, in which modeling decisions and results are shared with stakeholders through model development and application. This practice avoids a situation where the model fails to address the regulatory questions as conceived by the various stakeholders in the process.

Consistent with the above discussion concerning ongoing peer review and interaction between modelers and stakeholders and to reflect the recommendations of the Panel presented in more detail below, the Panel suggests an Alternative Figure 1 to the EPA's Figure 1 shown in the Draft Guidance (U.S. EPA. 2003). The Alternative Figure 1 represent the same general logic and information flow provided in the EPA's original Figure 1, but it has been amended to enhance the detail of some of the particular steps. It has also been expanded to represent the Panel's perception of the interaction with stakeholders in both the identification and specification of the problem to be solved and in the ongoing review of the quality of the regulatory modeling tools.

1.3. Problem Specification

The Panel appreciates the distinctions made in the Draft Guidance between model framework development and model application. Nevertheless, the Panel finds that this distinction is not consistently maintained throughout the document. For example, the terms "application tool" in Section 2 means problem-specific model implementation whereas "model application" in Section 4 means model based decision making. **The Panel recommends that the term application tool be replaced with "problem-specific implementation."**

The Panel believes that *Problem Specification* is a critical element of *any* modeling project. It guides the development of the conceptual model and it governs the model complexity. It must, therefore, include a clear and complete statement of policy, management, and/or scientific objectives, model spatial and temporal domain and resolution characteristics, as well as program constraints (e.g., legal, institutional, data, time and economics). This process must involve interactions among all stakeholders. **The Panel recommends that *Problem Specification* be given greater emphasis in the Draft Guidance by elevating it to a separate, initial step in the modeling process, as shown in the Alternative Figure 1 offered below.**

In accordance with this observation, the Panel offers the following suggestions that should be included for completeness and clarity in the expanded *problem specification* portion of the Draft Guidance for each of the above aspects of problem specification:

1) Regulatory or research objectives are statements of what questions a model has to answer. The statement of modeling objectives should include the state variables of concern, the stressors (model inputs) driving those state variables and their control options, appropriate time and space scales, model user acceptance, and, very importantly, the degree of accuracy and precision of the model. The discussion of Data Quality Objectives (DQOs) in the document is good, but the relationship

between total uncertainty and accuracy and precision of the model needs to be further clarified.

2) An alternative description of model types as a component of *problem specification* should compare and contrast: empirical vs. mechanistic, static vs. dynamic, simulation vs. optimization, deterministic vs. stochastic, lumped vs. distributed.

3) Specifying the model domain characteristics includes: identification of the environmental domain being modeled; specification of transport and transformation processes within that domain that are relevant to the policy/management/research objectives; specification of important time and space scales inherent in transport and transformation processes within that domain in comparison with the time and space scales of the problem objectives; and any peculiar conditions of the domain that will affect model selection or new model construction.

4) Problem specification should include a discussion of the potential programmatic constraints. These address time and budget, available data or resources to acquire more data, legal and institutional considerations, computer resource constraints, and experience and expertise of the modeling staff.

These factors, collectively, allow the modeler to determine the "complexity" of a model that is necessary and sufficient for the application under consideration (see recommended definition of model complexity in Charge Question 2 response).

1.4. Model Calibration and Sensitivity Analysis

The Panel applauds the overall treatment of model quality assurance and evaluation in Appendices B and C of the Draft Guidance. **However, the Panel recommends that the process**

of "model calibration" receive increased attention regarding guiding principles and best practices, both in the main text of the document and in the appendices. While calibration of air models may not always be feasible or justified, it is an integral part of water quality modeling and one of the more poorly understood steps in the modeling process. For example, the document could discuss how sensitivity analysis can be used during the calibration process.

Most process-oriented environmental models are underdetermined; that is, they contain more uncertain parameters than state variables that can be used to perform a calibration. Therefore, good model calibration practice uses sensitivity analysis to determine key processes for a given problem-specific implementation and then recommends empirical determination of the rate of those key processes as part of the calibration process in addition to measuring the time and space profile of relevant state variables. This practice can help further constrain a model for which parameterization by calibration is difficult. An example of this practice would be to measure the rate of photosynthesis (process) in a lake in addition to the biomass of phytoplankton (state variable).

1.5. Model Post-Audit

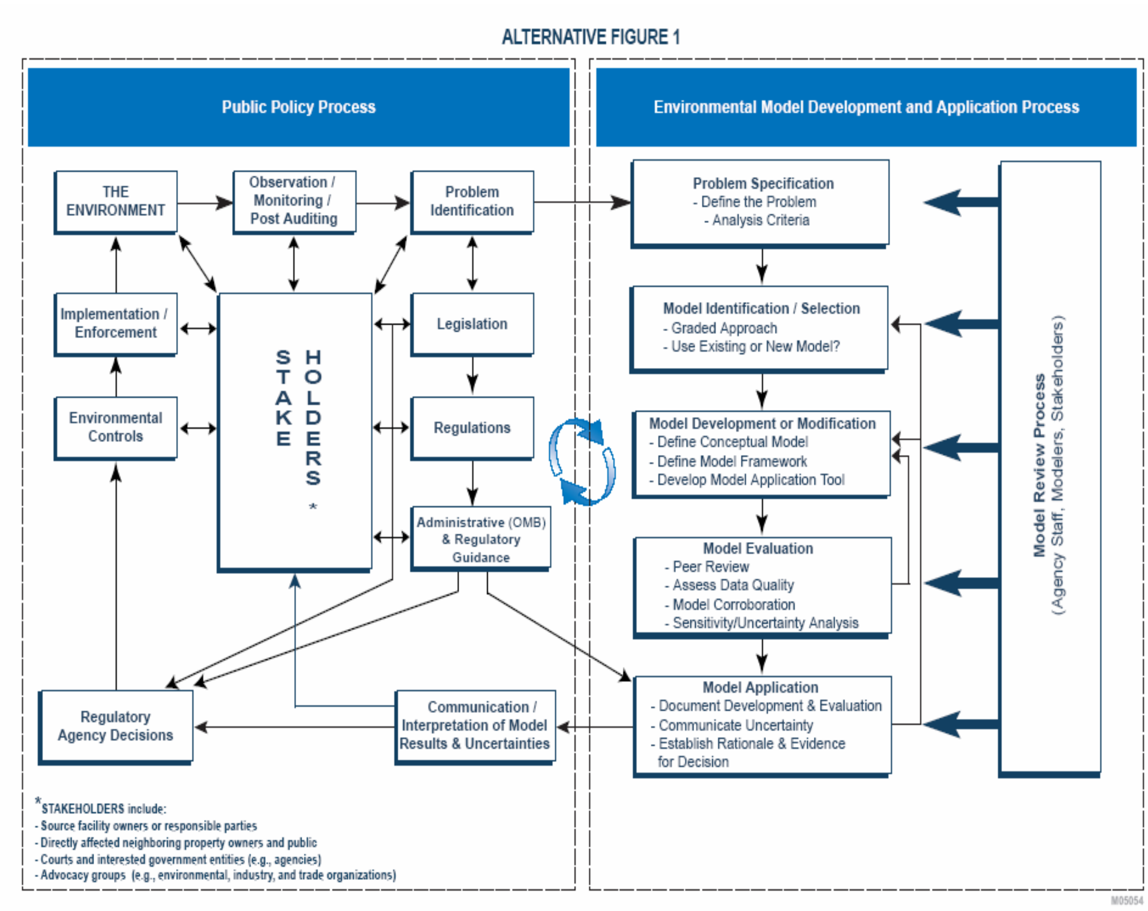
The practice of model post-auditing is defined as the ongoing observation of the response of the system to the actual implementation of a policy or management action relative to the model's forecast of how that system would respond, and is crucial to the ongoing improvement of environmental models. **The Panel recommends that the Draft Guidance acknowledge the value of post-auditing of models and associated data collection. This practice deserves a section of its own in the model application area (note the addition of a reference to post-auditing in Alternative Figure 1). That section should also discuss the role of regulatory modeling in adaptive management of environmental systems.**

1.6. Document Organization

The Panel believes that there are best practices for the development of a generic model framework (for example, WASP, QUAL2E, and AQUATOX) however most users of the Draft Guidance will *not* be model developers. Therefore, the document should contain additional best practices that should be followed for a site-specific or problem-specific implementation of a model framework. **In order to clarify the guiding principles that should be considered for each type of project, the Panel recommends that the Agency consider organizing the Draft Guidance according to the steps involved in carrying out a modeling project from inception to completion as indicated in Alternative Figure 1.**

The Panel identifies the steps in Alternative Figure 1 to be: Problem Specification; Model Identification/Selection (the document should recognize that a site-specific modeling project may be conducted by either new model construction or by selection of an existing model framework); Model Development (including problem- and site-specific model conceptualization, model formulation and configuration, and model calibration); Model Evaluation (through peer review, data quality assessment, model code verification, model confirmation/corroboration, sensitivity analysis, and uncertainty analysis); Model Application (including diagnostic analysis[2], problem solution, and application support for decision-making); and, after implementation of a regulatory action, Model Post-Audit. These activities should be covered in a QAPP for any given modeling project. Furthermore, the entire Modeling Process should be detailed in a report that includes documentation of all of the above steps in the process.

[2] Diagnostic use of models has great value for both model evaluation and problem-specific application. For example, plotting the cumulative distribution of observations of a state variable on the same plot as the cumulative distribution of model computation of that state variable on the same spatial and temporal scale is valuable for identifying whether the model is biased at high or low concentrations. As another example, development of a model mass balance diagram of a given state variable over appropriately chosen space and time scales (e.g., whole lake water column over the course of a year) is useful for identifying significant mass flow pathways, for addressing specific management questions, and for helping to guide monitoring programs.



Alternative Figure 1

On the left side, a few additional elements of the "public policy process" are suggested to clarify the stages of modeling that occur after a decision is made including the use of monitoring programs and post audit reviews of the outcome of previous or new regulatory actions to support model improvement. Alternate Figure 1 also expands on the role of models in supporting regulatory decisions, identifying needed environmental controls, and implementing these controls through enforcement actions when necessary. In addition, the centralized interactive role of all types of stakeholders is emphasized. These stakeholders include source facility owners and other responsible parties, neighboring property owners and other directly affected members of the public, courts and interested government agencies or related entities, and advocacy groups representing various environmental, industry, or trade organizations.

The expanded format for the right side of the diagram illustrating the Environmental Model Development and Application Process also maintains the same basic logic of the original EPA Figure 1; but the individual steps have been expanded somewhat including details for problem specification, model selection, model calibration and uncertainty analysis to represent the recommendations of the Panel.

Finally, the added emphasis provided by the addition of the continuous "Model Review Process" emphasizes the strong support of the Panel for the processes already occurring in much of the REM development program. **The Panel commends the continued and expanded application of this model review process to the further development of the Models Knowledge Base.**

2. GOALS AND METHODS

<u>Charge Question 2:</u> *Has EPA sufficiently and appropriately described the goals and methods, and in adequate detail, such that the guidance serves as a practical, relevant, and useful tool for model developers and users? If not, what else would you recommend to achieve these ends?*

2.1. Introduction

The general goals of the Draft Guidance are clearly stated (page 6), i.e., to provide guidance on how to assess the quality of regulatory environmental modeling. The assessment is to be made on the basis of a number of "performance criteria" or "specifications" (page 3) that characterize the three major components of regulatory environmental modeling; namely (1) model development, (2) model evaluation, and (3) model application. The Draft Guidance provides specific (and alternative) methods by which the performance criteria for each of these three components may be assessed.

The Panel agrees that the Draft Guidance is an excellent start to defining the process of and providing the measurement tools for quality assurance in regulatory environmental modeling. Furthermore, the Panel makes particular note of the critical importance of problem specification at the beginning of any modeling project. Problem specification supplies the modeling objectives and constraints that thereafter guide implementation of the modeling steps described in the Draft Guidance.

2.2. Intended Audience and Scope of Use

The Draft Guidance identifies the intended audience as being composed of two general categories: model developers and model users. Upon closer reading, however, other important modeling constituencies are explicitly or implicitly identified, each with distinctly different roles in the modeling process, leading the Panel to conclude that the term “model user” is overly broad and imprecise. For this reason, the Panel is concerned that the Draft Guidance elaborate on the distinction between the model users who generate model output (those who setup, parameterize, run, calibrate, etc, particularly with model framework software such as WASP or QUAL2E), and those who are managers and are principally users of model output. They are both users, but play different roles in regulatory environmental modeling, and as such are likely to use this Draft Guidance to assess different quality criteria. It would also help to clarify the intent of the Draft Guidance and its relationship to its different regulatory audiences (at least 2 groups): regulatory decision makers, and regional and state "assessors"/advisors for permit applicants. Panel discussions also suggested including other stakeholders in this audience, e.g., those to whom the results will apply or affect. For less experienced audiences, the Draft Guidance may be insufficiently explanatory. **The Panel recommends that the Agency clarify the use of the Draft Guidance for the variety of intended audiences and suggests that the Agency identify which sections will be most useful to the various stakeholders in a modeling project**.

A general concern about the overall Draft Guidance is its scope of use. The Panel finds that it provides a valuable resource to modelers in a wide range of disciplines, but unlike typical EPA guidance documents, it does not lay out a step-by-step course of action. Instead, it identifies a set of key “best practices” which should be adhered to, along with supporting materials. **Because this Draft Guidance differs in scope and content from other “guidance”, and because the term “guidance” has specific connotations in certain areas of model application, the Panel suggests that EPA consider using a term such as “guiding principles” instead of “guidance,” both in the body of the Draft Guidance and in its title.**

A second general issue related to the scope of the Draft Guidance is that much of the introductory parts of the Draft Guidance refer exclusively to regulatory applications of models, yet it is clear that the intent of the REM process is to bring consistency to all environmental applications of models, (e.g., regulatory support, research, resource assessment, evaluating alternative management actions, economic evaluations, etc.). **Therefore, the Panel recommends that the Draft Guidance, including its stated purpose, be revised to reflect these additional uses.**

A final issue regarding scope concerns the types of models to which the Draft Guidance is intended to apply. The executive summary states "this Guidance provides recommendations for environmental models drawn from Agency white papers, EPA's Science Advisory Board, and peer-reviewed literature." The Panel presumes that the intended application is to a broad range of models. However, this intention (if correct) is not clearly articulated in the "Scope of Guidance" in the Introduction to the Draft Guidance, nor are the classes of models (i.e., economic, behavioral, physical, scientific, engineering, or health models) explicitly identified. This concern is particularly apparent in the Models Knowledge Base (see also CQ5), where much of the information elicited is highly focused on models for pollutant fate, transport, exposure, and effects. Models that address economic activity, behavior, and emissions are differentiated by other key criteria, including whether they predict at the level of the individual, household, firm, sector, region, or national or global economy; whether they are normative (predicting how people *should* behave under various assumptions of rationality and information) or descriptive (reporting how people actually *do* behave); and whether they address the costs or benefits of environmental regulations.

Clearly the Draft Guidance is primarily intended to address regulatory environmental models, particularly those models used for policy analysis, national regulatory decision-making, and implementation applications. However, it should also be noted that it applies equally to a far broader category of models than its original targeted audience, and hence most of the Draft Guidance is expected to be useful for other modeling audiences as well.

According to the EPA's CREM home page, "The Models Knowledge Base is intended to be a living demonstration of the recommendations from the Guidance for Environmental Models. In this way, these two products work in tandem to describe and document good modeling practices." In pursuit of this goal, the **Panel recommends that the Draft Guidance clearly articulate the broad range of model types to which it is to apply earlier in the document, and ensure that the guiding principles for problem specification, model development, model evaluation, and model application reflect this diversity of types.**

2.3. Glossary

One of the keys to a workable Draft Guidance for quality assurance in environmental modeling is that the various modeling constituencies share a common language and definition of key ideas and terms. The Panel believes the Agency has made a commendable effort in attempting to establish a common vocabulary for the purpose of environmental modeling. The glossary is an excellent component of this Draft Guidance for providing the basis of that shared understanding.

However, there is room for improvement and a need for consistency, not only in the glossary, but also in the text. For example, some of the terminology and definitions are subject to multiple interpretations, which is to be expected for a document that combines vocabularies from a variety of fields. The Panel notes that the Draft Guidance's use of certain terms, e.g. "guidance," as described in the preceding section, is at times at variance with past definitions, including some of the Agency's own previous modeling documents many of which are cited in the references. The Agency should clarify the Draft Guidance's use of terminology and definitions that may not always be used consistently.

The current terminology used to describe graded approach needs to be clarified. For example, "managerial controls" should be replaced with a more generic terms such as "level of effort" or "allocation of resources." Another problematic area is the potentially misleading or overly generalized use of common statistical terms such as “reliability” and “sampling errors.” Where the Agency’s use of terms is intentionally different from prior or accepted use, they should be noted as such, and a brief, appropriate rationale should be provided.

The Panel suggests that the Glossary be expanded to include more terms to make it as comprehensive as possible. Some key terms that should be added are: “validation” (add a note: see model validation), “documentation,” “user manual,” “proprietary models,” “secondary applications”, “flow chart (code),” etc. Some panel members questioned whether the glossary definitions are the consensus of those in the Agency, or in the modeling community, or both? For example, “corroboration” is an interesting and appealing substitute for “validation,” but one that is not yet widely used in practice. Appendix A contains specific suggestions for enhancing the utility of the Glossary.

2.4. Model Documentation, Project Documentation, and User Manual

A variety of types and levels of “documentation” are required for a successful modeling project. The Draft Guidance discusses model documentation only in the model application component, i.e. a comprehensive project documentation to address “transparency” issues. (see box “Recommended Elements for Model Documentation”, in Section 4: Model Application, on page 26 of the Draft Guidance). However there is a need for model documentation during development, especially for complex modeling frameworks. In addition, the Draft Guidance makes no mention of the need for an adequate user manual (or user guide) for the “analyst” group of model users. It is unclear whether or not this is assumed to be part of the overall modeling project documentation. Some Panel members believe it is separate and distinct from model project documentation, and is essential.

In addition to the items already included in the box on page 26 of the Draft Guidance, the Panel believes it is important to note the need for documentation of choices made during model development, and for a model user manual.

3. GRADED APPROACH

Charge Question 3: *Has EPA sufficiently and appropriately proposed a graded approach, such that users of the guidance can determine the appropriate level of evaluation for a particular model use? If there are deficiencies in the proposed approach, what would you recommend to correct it, and why?*

3.1. Definition of "Graded Approach"

The concept of a "graded approach" is implicit throughout the Draft Guidance, as it should be. Usually "graded" is expressed implicitly through the use of the descriptor "appropriate." The term "graded approach" first appears under "Model Evaluation" (introduced on page 18). However, the graded concept applies to all phases of modeling—development, evaluation and application—not just evaluation. The Panel is concerned that the concept of a graded approach be introduced earlier in the document before the discussion of model development, as part of overarching concepts that are part of all of the modeling stages. **Accordingly, the Panel recommends that the material on the graded approach be modified to reflect that model development, evaluation and application should always be conducted using a graded approach that is adequate and appropriate to the decision at hand, as determined by the Problem Specification process described in the Panel discussion of Charge Question #1.** This introduction should then be followed by a brief discussion of how "graded" applies throughout the modeling process. For example, in the context of model development, "graded" refers to the extent to which existing models are modified to fit the problem specification or that screening models are used instead of more complex models.

3.2. Modeling Complexity and Associated Evaluation Needs

The scope (i.e., spatial, temporal and process detail) of models that can be used for a particular application can range from the simplest models to the very complex depending on the problem specification and data availability, among other factors. In addition to providing some additional comment on where the model continuum starts (i.e., what is the simplest model to be considered as a model in the REM Draft Guidance or in the Models Knowledge data base), the Draft Guidance needs to comment in more detail on the level of evaluation or "grade" of evaluation that might be appropriate for models of varying degrees of complexity. Currently, the discussion on page 18 dealing with the graded approach to evaluation is brief and the discussion of model complexity on page 11 only touches on evaluation complexity. In addition to the example of a "screening test" noted as a case where less rigorous model evaluation is required, examples of more complex situations should also be addressed in order to clarify the extended scope of evaluation that may be needed in different cases.

The Draft Guidance also needs to alert the reader that external circumstances can affect the rigor required in model evaluation. For example, in cases where the likely result of the modeling will be costly control strategies, court actions, or alienation of some sectors of the population, detailed model evaluation may be necessary. In those cases, all aspects of the modeling will come under close scrutiny, and it is incumbent upon the modeler to probe deeply into the model's inner workings (sometimes called "process analysis") to support subsequent regulatory decisions. This level of deeper model evaluation also would be appropriate when modeling unique or extreme situations not previously encountered.

The draft document should also note that gradation in evaluation can apply within complex model applications. For example, in modeling urban air quality, most areas use a regional modeling domain nested to provide higher resolution over the region of primary interest (e.g., Amar *et al.*, 2004). Clearly the most intensive performance evaluation should be directed towards the object of the modeling (the "fine grid"), but at least some level of evaluation should be applied to more distant areas (the "coarse grid"). **The Panel finds that the Draft Guidance acknowledges the scope and complexity of the models being used, but recommends that it provide more examples of appropriate evaluation steps for different models and model systems (i.e., combinations of models linked to address a particular issue) and for their particular applications. The Panel recommends that the Draft Guidance broaden the discussion of the graded evaluation approach to discuss evaluation requirements for additional circumstances such as using models in potentially litigious applications or in unfamiliar or unique situations.**

Model evaluation in most every situation basically involves expert judgment, examination of model output under changes in key driving variables, intercomparison with other similar models, sensitivity and uncertainty analysis and comparison with observational data. The Draft Guidance needs to discuss the appropriateness of using the more qualitative evaluation steps such as expert judgment to "screen" the model performance and application appropriateness (i.e., how well does the numerical model agree with the conceptual model under current and scenario conditions) before launching into more formal and complex, or higher grade, intercomparisons with observations or sensitivity analyses. In addition, the Draft Guidance should offer examples of some particular practical methods, complementary to evaluation (e.g., use of relative reduction factors and ensemble modeling) that can be used to address uncertainty in the decision-making process.

3.3. Evaluating Model Response

The Draft Guidance provides a comprehensive discussion of methods for evaluating a model's performance in terms of its ability to replicate historical situations. However, in regulatory applications the most important feature of a model usually is its response to changes in its input (e.g., response to growth and/or control of emissions). Aside from a discussion of post-audit, the guidance provides little direction for model users to evaluate whether a model will respond correctly to changes in critical inputs. Certainly a solid performance evaluation of how well the model replicates historical events, including analyses of the model's processes as well as its predictions, is an important component of evaluating its response. However, additional analyses focused on evaluating the performance of model response should also be conducted when the goal of the modeling is to predict a future state under expected or hypothesized changes to inputs.

EPA provides a good discussion on evaluating model response in its recently-released draft final Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-hour Ozone NAAQS [U.S. EPA, 2005]. Recommended techniques include retrospective analyses (similar to post-audit), use of various probing tools, comparison to observation-based models, and conducting sensitivity analyses for both the base and predictive cases using a variety of assumptions (a detailed discussion of these techniques is beyond the scope of this review). **The Panel recommends that the guidance be expanded to specifically discuss evaluation of model response, and to include suggested techniques such as those provided in [U.S. EPA, 2005].**

3.4. Use of Multiple and Linked Models

Many environmental problems require use of multiple models, with the models often linking together and interacting to varying degrees. For example, air quality modeling often links meteorological, emissions, and air chemistry/transport models. Integrated assessments that attempt to evaluate multiple, interdependent benefits and costs of a problem such as the overall value of the Clean Air Act as is done in EPA's studies on Section 812 of that act (U.S. EPA, 1997, 1999) and the work of the Grand Canyon Visibility Transport Commission (GCVTC, 1996) require linkage of a wide variety of atmospheric, environmental, economic and social models.

In cases in which multiple models are linked together to address a particularly complex issue, each model needs to be evaluated individually to assure that the model is being used within its proper domain and that it is performing properly in the context of the integrated assessment. In addition, evaluation of the full modeling system needs to take place to make sure that the overall analysis is adequate and appropriate for the application. Just because individual modeling components are behaving properly does not necessarily mean that the full system will provide authentic overall analyses. When using a system of linked models, it is essential to beware of compensating errors, which can lead to "getting the right answer for the wrong reason."

A classic example of compensating errors occurs in air quality modeling applications, where emission rates of pollutants are developed using an emissions model and meteorological parameters are generated with a meteorological model. Pollutant concentrations are then simulated using a dispersion model, using as inputs the emissions and meteorological model outputs. Modeled wind speeds that are too slow will lead to over-prediction of pollutant concentrations by the dispersion model, while modeled emission rates that are too low will lead to under-prediction of pollutant concentrations. These errors can counterbalance each other, producing modeled pollutant concentrations that meet accepted performance standards. But the fundamental flaws in the model formulation will likely cause the modeling system to respond incorrectly to changes in the inputs (e.g., application of emission controls).

The Panel recommends that the Draft Guidance acknowledge that many applications require the linkage of multiple models and that this linkage has implications for assessing uncertainty and applying the team of models. Each component model as well as the full system of integrated models needs to be evaluated for a given application.

3.5. Use of Model-Derived Data

The Panel commends the Agency for recognizing that the definition of data includes data sets generated from modeling exercises as well as from the literature and existing databases. However, the guidance also needs to clearly discuss treatment of uncertainty associated with the application of these diverse model-generated data as well as data sets derived directly from observations.

Data derived from modeling analysis that are then used for another modeling application also must be evaluated for uncertainties, caveats, and limitations in applicability. The evaluation then must be carried with the data throughout their future uses. One example of this need for propagation of data uncertainties and limitations is the use of emission inventories in regional air quality modeling. The emission inventories often are the result of complex data collection, analysis and emissions modeling. The inherent uncertainties in the emissions data and the emissions modeling need to be somehow quantified. Model users must recognize that the use of data as input for the next phase of modeling carries uncertainties, thereby impacting the next modeling steps. Sometimes, these uncertainties can be treated explicitly and quantitatively, but at other times the uncertainties can only be acknowledged qualitatively. Regardless, the uncertainties need to be noted and considered throughout the modeling system. This complex relationship between data and models needs to be discussed in the Draft Guidance.

4. PRACTICAL ADVICE FOR DECISION-MAKERS

<u>Charge Question 4:</u> *Has EPA sufficiently and appropriately provided practicable advice for decision-makers who must deal with the uncertainty inherent in environmental models and their application? What additional advice should EPA consider in dealing with uncertainty, and why? A number of researchers recommend a Bayesian approach to help decision-makers incorporate uncertainty into their decisions and to do so in a transparent fashion. Is the use of methods such as Bayesian networks an effective and practicable way for EPA decision-makers to incorporate uncertainty within their decisions and to communicate this uncertainty to stakeholders? If so, how? Are there alternative methods available?*

4.1. General Comments on Uncertainty

Experience suggests that shifts toward new, more informative, but potentially more complex, quantitative uncertainty assessment (QUA) methods inevitably present decision makers with challenges. A greater knowledge of uncertainty, absent an equally sophisticated framework for decision-making and communication, may only increase management challenges. More sophisticated QUA techniques do not automatically create more sophisticated regulatory decision-making. Thus the effective incorporation of uncertainty in decisions by decision makers, and the acceptance of these decisions by stakeholders, will not be accomplished with different or ever more elaborate QUA tools alone.

Specific methods for performing sensitivity and uncertainty analysis are discussed in Section C.5 and Section C.6, respectively, of the Draft Guidance. The guidance appropriately recommends a sequential approach to evaluating the sensitivity of the model to its components and boundary values, to be followed by more in-depth investigation of components and potential interactions that prove to exert the greatest influence on the variability of model outcomes. This is a sound recommendation for developing an understanding of sensitivity in complex models with many factors and many possible interaction effects among those factors. In addition to the work by Saltelli *et al*., 2000 cited in the report, other authors have proposed experimental test frameworks (Kleijnen, 2005) for formally examining sensitivity to individual effects and interactions in multi-parameter models. The matrix of statistical methods in Section C.5.7 provides a convenient comparison of the strengths and weaknesses of a progressively more complex set of approaches to sensitivity analysis.

The merits of various methods for QUA have been discussed, debated, enthused over, and at times derided, including everything from simple bounding analyses through 1-D and 2-D Monte Carlo analyses, to Bayesian techniques. However, the REM Guidance should remind readers that incorporation of uncertainty into decisions is not just a function of finding the right mathematical or modeling QUA "tool." Because scientists and researchers are often more comfortable focusing on the "hard science" of models/tools than on the "soft science" that governs the decision making process, often too little attention is given to problem formulation (in its fullest meaning), risk communication, or the perspective of decision makers (Thompson and Bloom. 2000). The panel cautions that searching for the "right" modeling tool (or uncertainty analysis) may miss the point; namely that models for regulatory purposes are a service to decision makers, and are not intended as a substitute for the hard task of selecting the "right" answer.

Before deciding on a QUA tool, it is incumbent on the modeler to seek input from decision makers and stakeholders as to how and to what extent they may accommodate uncertainty in their regulatory decisions. To a scientist, expressing and quantifying uncertainty is a good thing. But the single value has a long history of use in regulatory decision-making. Asking decision makers and stakeholders how they view scientific uncertainty, how they would like to see it expressed, and how they see it being used in the decision-making process is the necessary precursor to effective and transparent use of any QUA method. In short:

a) How much discretion does the decision maker have in addressing uncertainty? During policy development or for an action not directly governed by statute or rule, they may have considerable leeway to do so. Once a statute or rule is in place, they may have much less or no such leeway. Procedural regulations seem particularly resistant to incorporation of uncertainty. Many regulations work with reference to a fixed point (a "brightline" standard) and, despite an awareness that uncertainty exists in where this "fixed" point is actually located, decisions are simply based on whether or not the outcome is above or below that value.

b) How will stakeholders react to knowledge of uncertainty and how will this reaction shape the decision-making process? To a stakeholder, expressions of uncertainty can be taken as "you don't know," or could also imply inadequate effort, incompetence, or otherwise a lack of credibility of the responsible party, which undercuts support for regulatory decisions. Knowledge of uncertainty also allows opposing interests in a regulatory decision to focus on the highest or lowest value, regardless of its probability. Because there are often significant costs associated with choosing one specific value over another, arguments can erupt over differences in values that are, because of "uncertainty," statistically indistinguishable.

The definition of the term "uncertainty" has been a source of considerable confusion in EPA documents and discussions of models used in environmental risk assessment. The REM Draft Guidance attempts to clarify the use of the term by: 1) identifying types of uncertainty (model, data, application niche) in Section 3.1.3.1; 2) distinguishing uncertainty from natural variability in model inputs and parameters for different modeling applications; and 3) defining uncertainty analysis (parameters) as distinct from sensitivity analysis (model form and importance of model factors).

The Panel recommends that the Agency more clearly identify the various sources of uncertainty in model application, including:

a) **Stochastic variability**, over space, time, and/or from individual to individual. Uncertainty arises from incomplete or improper representation of stochastic variability and the associated uncertainty in future system outcomes (e.g., of weather);

b) **Model (structure) uncertainty**, including errors due to missing or improperly formulated process equations, inadequate spatial or temporal resolution, and incorrect model use;

c) **Model input uncertainty**, resulting from data measurement errors, inconsistencies between measured values and those used by the model (e.g., in their level of aggregation/averaging), and parameter value uncertainty; and

d) **Scenario uncertainty**, resulting from incomplete knowledge of current or future economic, regulatory, or physical conditions for which the model is applied.

In addition to identifying sources of uncertainty, the Guidance should also discuss the implications surrounding the propagation of uncertainties within model frameworks where models use the output of one model as input to another, or where model frameworks are assemblages of individual models.

The Guidance provides some useful but too brief advice (Guidance §4.1.2) on how this uncertainty might be effectively communicated to decision makers and stakeholders. Much more emphasis must be placed on performing a robust and iterative problem formulation with modelers, decision makers, and stakeholders and on correctly conveying model results using non-technical, non-quantitative, and non-condescending communication techniques.

Any transparency of QUA methods is only possible if decision makers and stakeholders are engaged early on by inclusive, effective communication and outreach strategies. **The Panel recommends that the REM Guidance should strongly advise modelers to begin model development or use only after they have obtained an awareness of how a decision maker plans to use the information on uncertainty that they will be providing. This is an important component of the Problem Specification as well.**

4.2. Sensitivity Analysis vis-à-vis Uncertainty Analysis

Section C.5 would benefit from improved clarity in the distinction between sensitivity and uncertainty analysis. For example, in Section C.5.1, the REM guidance obscures the distinction between the goals of sensitivity analysis and uncertainty analysis, where it states "…the distinction between these two related disciplines may be irrelevant" (p. 50). While the Panel agrees that the two are interrelated and sometimes confused, the distinction should be clarified in the guidance.

Sensitivity analysis is an examination of the overall model response to a perturbation of model inputs. The analysis thus can be used to inform model users, decision makers and stakeholders on where to focus the most resources in terms of developing a better understanding and characterization of the uncertainties for particular components of the model identified as "most sensitive" to perturbations of underlying model parameters. Rather than perpetuating any possible confusion between the focus or goal of these two analyses, the REM guidance should be more transparent in describing the purpose of each, their interrelationship, and the distinction between them**.** For example, the discussion in Section C.5.5 relating to Monte Carlo analysis currently reads more like a discussion of uncertainty analysis, rather than sensitivity analysis.

As noted in Cullen and Small (2004), sensitivity analysis is an important adjunct of uncertainty analysis, determining the impact of particular model inputs and assumptions on the estimated risk. Sensitivity analysis is often conducted as a precursor to uncertainty analysis, helping to identify those model assumptions or inputs that are important. If the model outcome is not sensitive to a particular input or set of inputs, there is no need to examine these inputs as part of a more sophisticated uncertainty analysis. Sensitivity analysis is revisited in the subsequent phases of an uncertainty analysis to identify those inputs and assumptions that are significant contributors to the overall variance of the output and/or critical to pending decisions (for an example of the latter, see Merz *et al.*, 1992), thereby identifying the uncertainties that matter. In this manner, priorities can be established for further research and data collection efforts. **Therefore, the Panel recommends that the guidelines articulate a more tangible set of alternatives for addressing model sensitivity/uncertainty. In particular, recommendations for uncertainty analysis should identify the need to focus resources on those processes to which the model state variables are most sensitive <u>and</u> are less certain in terms of their formulation and/or parameterization.**

4.3. Uncertainty Analysis Practices/Methods (REM Guidance Section C.6)

Section C.6 of the Draft Guidance on uncertainty analysis is incomplete in relation to the coverage given to sensitivity analysis in Section C.5. Returning to the discussion of types of uncertainty in Section 3.1.3.1, this section tries to address the “niche uncertainty” under the label of model suitability and “data uncertainty” through a weakly defined discussion of frequentist and Bayesian interpretations of probability. Unlike the rather detailed discussion of methods for corroboration and model sensitivity analysis, there is little true guidance on how to evaluate uncertainty in model parameters and the effect of this uncertainty in decision-making based on model outcomes.

The current Draft Guidance touches on the notion of a Bayesian framework and the use of prior knowledge and expert advice to reflect uncertainty in the model inputs (including parameter values). However, it does not distinguish carefully between Bayesian estimation of posterior distributions and associated inferences and decision theoretic approaches which incorporate explicit loss functions for certain errors in inferences. It would be very useful to have a “Box” example of an uncertainty analysis in which there is an established prior for an “uncertain” model parameter, a likelihood for the input data, and an updated posterior distributions and associated inferences and decision theoretic approaches which incorporate explicit loss functions for certain errors in inferences. It would be very useful to have a “Box” example of an uncertainty analysis in which there is an established prior for an “uncertain” model parameter, a likelihood for the input data and an updated posterior distribution for model parameters or predictions of interest. Thus, the Panel recommends that the REM Guidance (and MKB) **provide more practicable information through inclusion of “case study” examples of where and how EPA is currently incorporating uncertainty analysis in environmental models as an integral component of decision-making. In addition, the Panel recommends that Section C.6 be enriched to a level comparable to that of Section C.5 on sensitivity.**

The Panel agrees that Bayesian approaches are one of several candidate methods suitable for quantifying data uncertainty in appropriate situations. Bayesian methods are certainly appropriate for treating uncertainty in environmental modeling and may be particularly effective in modeling applications where empirical data on the distribution of model parameters in real applications are sparse and expert judgment may provide the most realistic assessment of the prior distributions. A Bayesian treatment of a simple model application or a more complex model with a network of dependencies (conditional relationships) is a theoretically appealing approach to incorporate prior uncertainty into posterior distributions of model outcomes (*e.g.* exposures, concentrations, expenditures, morbidity, mortality, *etc*.). Current software and iterative estimation algorithms have removed many of the computational barriers that once stood in the way of Bayesian treatment of a model application. Yet the removal of computational barriers does not eliminate the need for a solid understanding of the scientific basis for the model and in fact may require a heightened understanding (subjective, expert knowledge) of the prior distributions of parameters. Furthermore, adoption of Bayesian uncertainty analysis methods does not reduce the importance of sensitivity analysis to establish the importance of the model components and their interactions. The effectiveness of the Bayesian approach will be greatest when information on the prior distributions is accurate and new data to support the model application are plentiful. If the prior information is weak or uninformative or the amount of new data available for model parameter estimation is large, the model results will be dominated by the new data. If the new data inputs to the model are weak, the posterior distributions for outputs will be dominated by the prior distribution assumptions.

The Panel endorses the recognition that QUA should be an inherent consideration when using models to support regulatory decisions. Yet, given the enormous breadth of modeling paradigms (spatial and temporal scope and degree of complexity), the Panel remains cautious in its recommendations regarding specific methods of QUA (*e.g.*, “frequentist” vs. Baysian as suggested in the charge question). The nature and complexity of any particular model, its application within a particular regulatory program, availability of data and resources, *etc*. will all influence the choice of QUA that is appropriate. Thus, as with all other aspects of modeling, a graded approach is warranted for conducting uncertainty analyses. In some applications, simple sensitivity analyses may be all that is required. Regulatory decisions with far-reaching impacts should endeavor to use QUA tools to provide the public and stakeholder community with greater appreciation for the uncertainty range in the model output decision variables that ultimately define regulatory decision points.

4.4. Value of Information – Identifying "Uncertainties that Matter"

After identifying model inputs and assumptions that contribute significantly to variance in the output, it is necessary to consider how to use this knowledge (Cullen and Small, 2005). Value of Information (VOI) techniques seek to identify situations in which the cost of reducing uncertainty is outweighed by the expected benefit of the reduction. In short, VOI is helpful in identifying model inputs that are significant because: a) they contribute significantly to variance in the output, and b) they change the relative desirability of the available alternatives in the decision under consideration. **The Panel recommends that the REM Guidance acknowledge the potential utility of VOI techniques available to assess the importance of the variability and uncertainty contributed by individual inputs to the expected value (or conversely, the "loss") associated with a decision under uncertainty** (Raiffa, 1968; Morgan and Henrion, 1990; Finkel and Evans, 1987; Massmann, et al., 1992; Dakins et al., 1996; Yokota and Thompson, 2004).

While the Panel understands that the REM guidance is not intended to be proscriptive in its effort to provide an overview of QUA methods, it does not provide sufficient context currently for an end user (e.g., modeler within the regulatory community) to be able to determine the level of QUA that would be appropriate within a particular context or application. Without being proscriptive, the REM Guidance could consider providing a more concrete decision framework to help guide the choice of appropriate/available QUA methods. As a starting point, the REM Guidance should include examples of, or references to, the nature and degree of QUA currently being implemented or adopted within various EPA programs. For example the Panel is aware of the extensive uncertainty analysis that is an integral component of the 3MRA model. While it is clear that this one example should not be taken to endorse a particular QUA, the MKB would provide one means of assembling a "library" of such examples with the nature of the QUA, the data requirements, limitations, *etc*. This would provide at least some options by way of example that model users and decision makers could turn to as a resource beyond the cited statistical references.

The appeal of QUA is that it can be used to provide quantitative estimates of the "degree of confidence" when using model results as a component of regulatory decisions. Nevertheless the results should be presented with some caution. It might be tempting to assign a high degree of confidence in the uncertainty analysis based on the adoption of a highly elaborate or complex analysis. Yet, the validity of the QUA is of course dependent on the quantity and quality of the information available for the analysis. The choice of appropriate QUA method (frequentist, 1-D *versus* 2-D Monte Carlo, Bayesian, *etc*.) can only be made if the intended audience of the REM Guidance understands the data requirements and associated level of effort to conduct the analysis of the various types of QUA. As compared to the REM Guidance describing best practices for model development/evaluation, the guidelines do not contain a similar set of "best practices" for evaluating, presenting, and incorporating model uncertainty in decision-making. **While references cited in the REM Guidance provide an array of applicable methods to address model uncertainty, the draft guidelines do not provide sufficient discussion, context, and recommendations necessary to provide a model user/decision-maker with "practicable" information relating to appropriate uncertainty analysis methods and how to convey the results of such analyses.**

The Draft Guidance should offer some practical methods that can be used to address uncertainty within the decision-making process. For example, one is the concept of Weight-of-Evidence (WoE), in which the model is only one (albeit an important) component in a suite of analyses feeding into the decision framework. A second possible approach is to use of the model in a relative, rather than absolute, predictive mode. This approach uses "relative reduction factors" multiplied by observed (measured) conditions in place of absolute predictions. In theory, such an approach can avoid or cancel out systematic biases in the model formulation, hence reducing the uncertainty in the predictions used for decision-making. A third example approach to dealing with uncertainty is the use of ensemble modeling. This approach involves running several different models and using a composite of the results. While ensemble modeling can be very resource-intensive, it is worth considering for applications or decisions involving extreme cost or risk. These example approaches could be included, among others, with the REM Guidance to provide decision makers practical examples of methods incorporating uncertainty in the decision framework.

4.5. Communicating Uncertainty

Independent of the choice of particular QUA tools, **the Panel recommends that the REM Guidance provide more discussion on the importance of the manner in which results of QUA are communicated to the decision maker (and public/stakeholders).** Graphical methods often serve to convey complex statistical/probabilistic results in a more understandable manner, and the REM Guidance should consider including a range of examples in the document. Again, the MKB may be useful as a library of such examples.

As the analyst/modeler and decision maker are usually not the same individual, it is important to accompany results with the key assumptions and caveats encompassed in the analysis. How can uncertainty or probabilistic results be interpreted to help identify the uncertainties that matter most, and to point the analyst to further study or data collection activities that can be most beneficial in reducing these critical uncertainties? As noted earlier, most often only a relatively small subset of inputs is responsible for a majority of the variance in a model output. Morgan and Henrion (1990), Cullen and Frey (1999) and others describe the use of summary statistics, visual methods, regression approaches and other sensitivity analysis tools to help find the most important input uncertainties. Broader approaches for risk communication and methods for testing the effectiveness of alternative presentations are discussed in Finkel (1990), Bostrom et al. (1992), Morgan *et al*. (1992), Fischhoff *et al*. (1998), Thompson and Bloom (2000), and Cullen and Small (2005).

The preponderance of QUA methods focus on what the REM Guidance defines as "data uncertainty." Quantitative "model uncertainty" and "application niche uncertainty" present significant challenges that are rarely feasible to address. In addition, empirical or observational data are themselves subject to uncertainty depending on the quantity and quality of those data, and it is important to recognize these uncertainties in the context of evaluating the importance of model uncertainties. In the case of directly observed data, there are uncertainties associated with the measurement techniques and with the data analysis processes themselves. In the case of data that are generated by modeling, uncertainties arise as a result of modeling analyses that produced the data. A common example is the difficulty of comparing environmental data collected at a particular point in time and space, to a model prediction based on averaged conditions for a grid cell with spatial parameters and time steps necessarily much different from the conditions under which the measurement was made. As discussed earlier, a clear description that discusses the main sources of uncertainty, including an indication of the types of uncertainty that are most readily addressed, would be helpful in communicating these concepts to the reader. **Therefore the Panel recommends that the REM Guidance be clear on the types of model uncertainty that most QUA tools address.**

These data uncertainties mean that using data to evaluate models is very much an imperfect process. As a result, the discrepancy between observed data and model simulations does not mean that the model is wrong or not useful. It is particularly important to communicate this concept to decision makers who may favor discounting modeling results if the comparisons between observations and models are less than perfect. In addition, when analysis of data is used in lieu of modeling results because the modeling results do not completely agree with observations, the potential errors and/or uncertainties in the data used for the analysis must be acknowledged. In some cases these uncertainties actually may be more significant than the uncertainties determined for the modeling itself.

The complex nature of data uncertainties and modeling uncertainties needs to be carefully communicated to decision makers. **To promote this discourse as part of the general practice of modeling, the Panel recommends that the Draft Guidance should stress the importance of communicating model sensitivity and uncertainty both in the context of model evaluation and when interpreting and applying model outcomes in the context of decision-making.**

5. IDENTIFICATION AND STRUCTURE OF OPTIMAL SET OF INFORMATION FOR ALL USERS

Charge Question 5: *The Panel should consider that environmental models will be used by people whose technical sophistication will vary widely. EPA has therefore attempted to cull information about models that broadly serve the needs of all users, using a data template to collect this information (see Attachment D). Has EPA identified, structured and developed the optimal set of information to request from model developers and users, i.e., the amount of information that best minimizes the burden on information providers while maximizing the utility derived from the information?*

5.1. General Comments and Suggestions

As indicated in Attachment D of the MKB (included in this report as Appendix B), the major categories of information collected for the models in the REM Models Knowledge Base include:

A. General Information, regarding the model name, contact information, overview, and web link;

B. User Information, concerning technical requirements and basic guides for obtaining and using the model;

C. Model Science, including the conceptual basis for the model and discussion of evaluation steps that have been undertaken and documented for the model (code verification, corroboration with observed data, sensitivity and uncertainty analysis); and

D. Model Criteria, summarizing applicable regulations and the problem domain(s) addressed by the model, including types of pollutants, sources, environmental media, and key fate and transport and exposure and effects processes.

The information targeted in the current data entry sheet addresses most of the critical elements needed by potential users to assess the overall relevance and utility of a model in the MKB, and does so in an effective and efficient manner. However, some additional general subcategories of information should be added to the data entry sheet.

A. General Information

The general information entries for the MKB data sheet include:

1. Model Name,
2. Model Overview/Abstract,
3. Contact Information, and
4. Model's Home Page.

This information is appropriately informative and concise, and the examples we considered in the current MKB provide useful introductions to the models.

B. User Information

The user information entries include:

1. Technical Requirements
    a. Computer Hardware,
    b. Operating Systems,
    c. Programming Languages, and
    d. Other Requirements and Features.

2. Download Info (with URL)
3. Using the Model
    a. Basic Model Inputs,
    b. Basic Model Outputs,
    c. User's Guide, and
    d. Other User Documents.

The information requested is useful and appropriate. Most users will not need to know the programming language used by the model, since they will access, download, and use an executable version of the model. Nonetheless, this information could be useful for some users and provides a useful context for system requirements. The MKB should indicate whether the underlying programming language(s) must be obtained or licensed for use of the model.

Under the "Using the Model" section of the data entry, the Panel believes that it would be useful to indicate the level of expertise, both environmental and computer, needed to understand and use the model, and the level of user support provided for the model by its developers, the Agency, or other sources. This information is provided for a number of the models currently in the MKB as part of the User's Guide or Other User Documents fields. Still, it would be useful to explicitly ask for this information as part of the data entry sheet.

C. <u>Model Science</u>

The model science categories include:

1. Conceptual Basis of the Model,
2. Scientific Detail for the Model,
3. Model Framework (equations and/or algorithms), and

4. Model Evaluation (verification (code), corroboration (model), sensitivity analysis, uncertainty analysis).

The requested information addresses many of the key elements needed to document and assess the scientific basis for a model. **However, the Panel does recommend some modifications and additions to the list above. First, defining the Model Framework as the 'equations and/or algorithms' for the model (as is also done in the Model Glossary) appears counter to the usual use of the word "framework." This term is usually associated with the broader conceptual basis for the model or (by some, see the U.S. EPA, 2003 and in particular, EPA's Modeling QAPP Draft Guidance, page 54) as "the model and its supporting hardware and operating system." A clearer request for the underlying model equations and/or algorithms would be provided using the descriptor "Model Structure and Calculation Methods." Second, the mention of corroboration (model) under Model Evaluation should explicitly mention the model's ability to predict observed monitoring data.**

The Model Evaluation section of the Model Science entry considers many of the key issues needed to evaluate the scientific rigor behind the underlying model development and previous applications, and addresses many of the elements of good modeling practice that are emphasized in the Draft Guidance. Indeed, the Panel views an important purpose of the MKB as providing an incentive for model developers and purveyors to conduct and openly communicate their efforts in model evaluation. **From this perspective, the Panel recommends some additional pieces of information that should be elicited and reported, including:**

1) **<u>Documented examples of peer review for the model</u>, including reviews conducted by the EPA, other agencies or panels, and papers presented in the peer reviewed literature. Key limitations**

and needs for improvement that were identified in these evaluations should be reported, and

2) <u>**Benchmarking studies**</u> **in which the model's predictions and/or accuracy were compared with other models.**

The Panel also recommends the inclusion of a section, following Model Evaluation, for the model developer to summarize key limitations of the model and plans or needs for modifications and improvements. This type of self-critique would be both informative to users and motivating to the ongoing improvement of the models in the MKB.

D. <u>Model Criteria</u>

The model criteria elicited and reported include the major categories of:

1. Regulations,
2. Releases to the Environment,
3. Ambient Conditions,
4. Exposure or Uptake, and
5. Changes in Human Health or Ecology.

The Panel notes that the criteria elicited are highly focused on models for pollutant fate, transport, exposure, and effects. Much of this information is not appropriate for models that address economic activity, behavior, and emissions. These models are differentiated by other key criteria, including whether they predict at the level of the individual, household, firm, sector, region, or national or global economy; whether they are normative (predicting how people *should* behave under various assumptions of rationality and information) or descriptive (reporting how people actually *do* behave); and whether they address the costs or benefits of environmental regulations. As such, the

Criteria should first note the genre of the model, whether economic/behavioral vs. physical or engineering science models (though some models, e.g., for predicting emissions, could combine elements of both), and include different subsets of information for these.

5.2. Specific Suggestions by the Panel

A. Under Regulations, those entering information into the MKB should be given the opportunity to identify "Other Regulatory or Decision Support Applications." These could include US regulations, such as NEPA or Natural Resource Damage Assessments under CERCLA, or international agreements or treaties, such as those for ocean disposal or controls on persistent organic pollutants (POPs). It could also include non-regulatory decision support applications, such as for risk communication efforts by state environmental or public health agencies, or life-cycle assessment in support of green design decisions by firms.

B. Under the Releases to the Environment Section, a differentiation should be made between models for natural systems (emphasized in the current list) and engineered environments, such as buildings, treatment plants, and water distribution systems. (Models for the latter, such as EPANET, have received increased attention in recent years due to concerns regarding drinking water quality at the tap from accidental contamination and homeland security, and should be sought for inclusion in the MKB.) Also, under Source Type, area source models should be explicitly noted to include larger scale sources, e.g. for non-point source runoff in watersheds, biogenic emissions in regional air quality models, or distributed natural or anthropogenic sources to groundwater.

C. Under Ambient Conditions, the Panel feels that the terms included under Processes (transport, transformation, accumulation, and biogeochemical), while useful information for many fate-and-transport models, is specific enough that it need not be included in these general model criteria. The Panel suggests that this information be replaced with the following, more-general criteria:

Time scales addressed in the model and whether the model predicts for dynamic or static conditions

1) Spatial scales or economic units addressed in the model and whether it provides a primarily distributed vs. lumped representation of the modeled system, and
2) Whether the model is deterministic, predicting single values for model outputs, or stochastic, predicting a range or distribution of values to characterize variability and/or uncertainty.

D. Under Changes in Human Health or Ecology, the options should be expanded to include natural resource or materials damage, to consider effects, e.g., on visibility, historic buildings, or property value.

E. Model Applications: In addition, the Panel recommends that an additional major category of information be elicited and reported (in addition to the major items A-D). The additional category would be listed as "E. Model Applications," and point site users to specific examples of regulatory or non-regulatory applications of the model (distinguishing between the two) in the public record and the peer-reviewed scientific literature.

5.3. Track Versions of Models

The Panel recommends that revision tracking be incorporated into the MKB. Such a feature would have several benefits. First, it better reflects the realities of modeling than the current framework in which models are implicitly treated as unchanging. Second, it facilitates a tighter connection between policy analysis and modeling: the documentation for an analysis would specify a particular model version whose characteristics could be retrieved from the database. Third, it would provide valuable insight into the evolution of models over time. It would be possible to observe the extent to which changes in a model are driven by: developments in the underlying science; the availability of new data; the availability of new software or algorithms; the demand for new features; and the correction of programming bugs.

Revision tracking could be implemented as follows:

a) <u>A version field and a date field would be added to the data entry form.</u> The contents of the version field would be a character string supplied by the model developer. The string should contain enough information that the developer (or a subsequent maintainer) could reconstruct and rerun that version of the model at a later time. The date field would be the date at which that version of the model was released or placed in service, and

b) <u>Each time a new version of the model is added to the database, there should be one or more fields describing the significant changes in the model from its previous version.</u> In addition, all other fields associated with the model should default to their settings from the previous version. However, it should be possible to provide an updated version of any field without losing the corresponding field from the previous version of the model.

The documentation burden imposed on model developers would be small. In particular, models whose development has been sponsored, at least in part, by EPA will already have significant changes spelled out in grant proposals or cooperative agreements. Ideally, the MKB would also include information on bugs fixed between versions. With revision tracking in place, the main page for each model would have a link to "Previous Versions," which would take users to a page showing the dates and revision numbers of all previous vintages of the model in the MKB. Each previous version should be a clickable link showing the list of changes embodied in that version (from above) and include links to other information specific to that version of the model.

5.4. Listing of Key Publications and Applications of Models

The Panel believes that it would be useful to include a list of key references for each model: publications and reports where the model is described or documented, and important applications. Model developers will be able to provide this information easily and it will allow potential users to: (a) find out more about a model; and (b) avoid duplicating previous research; and (c) see example applications. This information would also address the concern raised in charge question 7c by showing how widely used and thoroughly peer-reviewed each model is.

5.5. Clarification of MKB Entry Sheet Items C1-C3

The distinction among items C1, C2, and C3 in the MKB Data Entry Sheet should be made clearer, and the information requested by these items should correspond more closely to the parallel sections of the Draft Guidance that discuss this information. Question C1 and C3 are intended to match Section 2.2 and 2.3 of the Draft Guidance but most model builders and users will probably regard those sections as overlapping considerably. Section 2.2 (Conceptual Model Development) in the Draft Guidance, for example, requests a clear statement and description of each element of the conceptual model, plus documentation of the science behind the model, including: its mathematical form, key assumptions, the model's scale, feedback mechanisms, etc. It seems, in short, to be asking for essentially complete documentation for the model. Because of such great breadth of coverage, the types of information covered by Section 2.2 are solicited by items C1, C2, and C3 on the Data Entry Sheet. Subsequently the Draft Guidance, Section 2.3 (Model Framework Construction), begins with a discussion of some of the same information: a formal mathematical specification of the concepts and procedures of the model. Assuming information provided under C3 is intended to parallel that discussed in Section 2.3, it is not clear how the mathematical formulation requested here differs from that requested under C1.

It appears that the intent of C1-C3 is the following. The answer to C1 would be a broad conceptual overview of the model that would be relatively free of technical detail (no equations) and would be accessible to readers from a wide range of backgrounds. It would usually include a diagram showing the relationship between major components of the model. The answer to C2 would provide the technical detail missing from C1 (namely, the model's key equations) and would have specialists as its intended audience. It would provide the theoretical basis for the model. The answer to C3 would describe the model's numerical implementation (data, algorithms, computer programming). This approach would be useful but needs to be spelled out more clearly in instructions accompanying the form. It would also integrate well with version tracking: the answer to C3 will usually change with each revision of the model; the answer to C2 will change periodically; and the answer to C1 – which defines the essence of the model – will generally be stable.

6. DATA DICTIONARY AND DATA STRUCTURE

Charge Question 6: *EPA has developed a data dictionary and database structure to organize the information it has collected on environmental models (see Appendices E and F of the Draft Guidance). Has EPA provided the appropriate nomenclature needed to elicit specific information from model developers that will allow broad inter-comparisons of model performance and application without bias toward a particular field or discipline?*

6.1. General Comments

The discussion of the elements of this question is based primarily upon relatively terse, and sometimes vague, information provided by the REM Data Dictionary and the REM Entity Relationship Diagram. The Panel's review of the Data Entry Sheet (CQ5) and related documentation of several individual models appearing in the REM Models Knowledge Base (MKB) were also considered in this question. **This has led the Panel to recommend that the technical issues concerning the specific design of the MKB be addressed by either (a) a separate knowledge base topical report, or (b) an additional appendix to the current Draft Guidance, to allow the main report to concentrate on the Agency's overall plan for the use of this important tool, without ignoring the details of its functional design.**

The Panel's expectation is that the developers of the MKB database structure would also perform the necessary QA review of their Data Dictionary and entity relationships to assure that they are properly drawn and functioning. This aspect is virtually impossible for the Panel to evaluate thoroughly on the basis of the limited details provided on the database structure in the two documents provided. It is similarly difficult for panel members (who are not information technology specialists) to provide much useful advise without a better understanding of the strategy and implementation of the design. Perhaps the separate topic report or MKB Appendix could include all of this definition information and an outline of the database design strategy. Panel members were not sure this would be helpful. As noted below, review of the individual model documentation in the MKB provided the Panel with the most insight on the effective results of the application of these tools within its system.

Although the Glossary presented in Appendix A of the Draft Guidance is an undisputed "plus" for the documentation effort, there are very few of the terms in the Data Dictionary repeated there, as may be expected and appropriate, given the specialized nature of database terminology that is usually unique to the particular database software program for which it was specified. For a database, its functional terminology use has to be clear and internally consistent, regardless of its conformance to the "outside world." It has been noted elsewhere that several of the Glossary terms have varying definitions, as used in different sections of the Draft Guidance and MKB references—even though they are intended to conform to the Guidance definitions put forth in the Glossary. Although it initially appeared that ongoing efforts may have to include variant definitions (with footnotes to indicate model association); the use of "special guidance-specific" definitions for some terms may be satisfactory if the authors of the guidance carefully review their use of terminology for consistency of use, and alter the text accordingly. As suggested above, however, the MKB Data Dictionary can function independently and quite satisfactorily, as long as the translation of the Data Entry Sheet terminology to database definitions is precisely specified. **The Panel therefore recommends that the Agency follow its own standard QA/QC program procedures for ensuring quality of the all of the underlying information in the MKB system.** From evidence presented to the Panel, it appears that this has already been substantially completed for the functions currently defined. As new functions are added to support new features, including those recommended elsewhere in this report, it will of course be necessary to expand and update this Data Dictionary and repeat many of the QC checks to verify functionality.

The Panel has varying opinions on whether the overall Glossary should include all of the Data Dictionary terminology to assure that referencing is clear to all users. For the reasons outlined above, it appears as though this would potentially add more opportunity for confusion than enlightenment. **Therefore, the recommended approach that would isolate the Data Dictionary in its own self-standing report would seem most advantageous at the current time.** Regardless of the location of this documentation, the Panel re-iterates its encouragement to extend the QA/QC procedures followed to establish the initial quality of the MKB into the larger QA program needed to maintain the information, as well as the hardware and software systems needed to implement it.

6.2. Model Performance Information

This charge asks about including database information that is “unbiased.” However, as indicated by the presentations made by Region 5 and 10 representatives on February 7, 2005 there is also a need for a place in the database for additional “classification” information, which may go beyond that requested from the developer, and which may appear “biased,” if it includes “recommendation” information. This would be a subsection of the database specifically devoted to information that helps Agency regulatory-model application staff and “outside applicants” to identify the “most appropriate” candidate models. (A new “model selection program” that is under development by ORD was demonstrated at the Panel’s review meeting. It appeared to be a potentially valuable tool, but several Panel members cautioned that it should produce an output file that includes a matrix of candidate models, rather than a single “recommendation,” so that the user of the tool can more fully consider which of several candidates best fits the problem application at hand). Much final model-selection decision making is presently achieved by regional or state agency discussions that come to agreement on the most appropriate site-specific model choice for major projects at a particular decision point. However, as noted further below, the MKB would be more valuable, if cumulative EPA problem application experience could be more consistently represented in the database, along with the present basic model description information.

The Panel is in concurrence on the importance of eliciting and including information on historical model performance and particular application experience from various model users (both other modelers and decision makers), as well as model developers. This was not especially motivated by any desire to minimize "biases" in reporting. There was some concern that developers of a model may not be in a position to fully (or objectively) judge its behavior in various contexts. Avoiding or minimizing bias would seem to require gathering reviews from as broad a user base as possible. It now appears that the current approach, which utilizes only information volunteered by the model developers, would tend to ensure that individual "biases" are included, without any real opportunity to neutralize them. This situation may be the unintentional result of using a more open narrative format for developers to explain features of the model. It may be noted that the Panel review of the current Data Entry Sheet, the Data Dictionary, and the Entity Relationship Diagrams did not suggest that there were any particular features that would "bias" the selection or representation of models. Instead, as noted both above and below, the reviewers were interested in seeing more information, as this could include application experience with "competing" models.

In fact, the inclusion of additional information on the history of performance suggested by several Panel members would be more likely to include "opinions" as to the quality of performance, hopefully supported by comparison with appropriate measurement data sets. This extra information was viewed as important to prospective model users, even though it would be likely to also include some "biased" information. As long as instances of "preconceptual bias" can be identified and flagged or filtered, the availability of previous application experience (especially successes) would be a valuable component of the MKB information set. (Given the wide variety of models included, this "openness" may be helpful to both agency and "outside" users; but perhaps some form of warning of the risk of potential bias should be included with any new "performance history " element, so that the new users are fully aware of this limitation). **The Panel recommends that the Agency clarify the intended roles of the "inside" and "outside" users of the MKB system and how that affects the priorities for the user interacting with the system (including supplemental, even if "biased," application history information).**

6.3. Additional Recommendations

To address details issues of CQ 6 more specifically, the Panel reviewers observed that the dictionary and database do capture much of the information necessary to assess model performance; but there were some noted exceptions:

a) <u>CONCEPT:</u> This results from problem formulation, but may or may not convey to the user useful information about the problem or set of problems (Draft Guidance §2.1) for which the model was developed. Another field should be added, "*Problem Specification*" (as noted in Section 1.2 of this review, to concisely capture descriptive information about the original application problem.

b) <u>DECISIONDOCS:</u> As written, this field seems to focus on how to use (run?) the model, how to produce output, and what experience there has been with running the model. This (or a new) field should include information or links to examples of when, how, and where the model was used to support an actual decision or decisions. Qualitative opinion on how the model performed would be acceptable/desirable. What benefits and problems did decision makers and stakeholders experience when using the model? This element should include a date entry so potential users can better judge the currency of the model.

c) DOWNLOADINFO: This should include information on the size of the model (zipped and unzipped), whether it is one file or a collection of files, and whether its setup will require changes in system files.

d) DIR ENTRY STATUS and REVISION_DATE: It is not clear what is meant by "last reviewed" — whether the date given would be for when the model itself was reviewed or when its entry into the dictionary was last updated? There should be information on when the model itself was last reviewed by its developer, as well as documentation (or links to such) of any and all changes, including errata and enhancements. It would also be useful to have documentation of problems encountered or improvements suggested by actual users of the model. All of this may be considered in MODELCONTACTINFO but the database appears to be placing any "institutional memory" of the model's behavior in a person, who may or may not be available. The reviewers thought that there should also be fields consistently indicating whether model documentation is available online, who is responsible for preparing and maintaining this documentation, and the date it was last reviewed and/or updated.

e) EVALUATION includes four questions, but without performance information, the first three seemed less useful (recognizing that they might represent the only information available for newer models).

f) MODEL_CATALOG Table information given in Data Dictionary is too cryptic to tell whether any model performance information would fall into the descriptions provided there, and

g) PROG_LANGUAGE: This should also indicate whether any other software (particularly proprietary, e.g., ArcINFO) is required to operate the model.

Panel reviewers considered their observations in reviewing the **Aquatox, CalPuff, IPM,** and **TRIM_FATE** models in reaching their conclusions about the performance of the identified database elements. Overall, the construction of the system appeared to be generally well-designed, but with opportunity remaining for expanding its focus to include more consistent information on model use experience and performance in a format that would make it more uniformly easy for users to compare models of interest for a particular candidate application. There are several key features that the Panel would like to see improved or expanded so that the MKB can be most effectively used by the EPA and its stakeholders. The existing Data Dictionary and Database Structure appear to be adequate to address existing features of the current MKB. However, as this tool is expanded to include new features recommended by either this Panel or the Agency's developers, it will be necessary to add new structural elements and data elements; and this will require an ongoing additional QA/QC effort. **Therefore, the Panel recommends that the following issues should receive further consideration and attention:**

1) **A consistent QA review of the current content of the information contained in the MKB [some model feature/description errors (at the user interface level) were noted by Panel members, see Appendix C of this report],**

2) **Follow-up requests to developers who supplied original information to supply missing data for the minimum set of descriptors that the Agency decides are essential to proper model selection,**

3) **Entries into the data dictionary be clearly defined and made as consistent as reasonably possible, with the text in the Draft Guidance and data entry forms, and**

4) **Provision of a mechanism that actively solicits feedback from the user community regarding application experience and model performance, both inside and outside the Agency, beyond voluntary e-mails to designated contacts for individual models.**

7. QUALITY OF INFORMATION PROVIDED ABOUT THE MODELS

Charge Question 7: *To facilitate review for this particular charge question, the Panel should focus on three models that represent the diversity of model information housed within the Models Knowledge Base. These models are: (1)* ***Aquatox,*** *a water quality model; (2)* ***Integrated Planning Model (IPM)****, a model to estimate air emissions from electric utilities; and* ***NWPCAM****, an economic model.*

Using these three models as examples and emphasizing that EPA is not seeking a review of the individual models, but rather the quality of the information provided about the models, EPA poses the following questions to the Panel. Through the development of this knowledge base, has EPA succeeded in providing:
(7a) easily accessible resource material for new model developers that will help to eliminate duplication in efforts among the offices/regions where there is overlap in the modeling efforts and sometimes communication is limited?
(7b) details of the temporal and spatial scales of data used to construct each model as well as endogenous assumptions made during model formulation such that users may evaluate their utility in combination with other models and so that propagation of error due to differences in data resolution can be addressed?
(7c) examples of "successful" models (e.g., widely applied, have been tested, peer reviewed etc.)?
(7d) a forum for feedback on model uses outside Agency applications and external suggestion for updating/improving model structure?

7.1. General Comments

The Panel commends the Agency for developing the Models Knowledge Base and strongly supports its continued improvement. This type of resource has been needed for some time and even in its draft form, the Models Knowledge Base (MKB) provides an easily accessible resource for the modeling community that, if maintained and used, will significantly improve the development and application of models both internal and external to the Agency.

In answering questions 7b-7d, the Panel focused primarily on two suggested models (i.e., AQUATOX and IPM) along with a third model selected by the Panel (CALPUFF). (The choice of models was governed by the past experiences of Panel members.) However, it was necessary to go beyond these models to address Charge Question (CQ) 7a. The Panel interprets CQ 7a as being asked in the context of a model developer who might use the MKB to screen existing Agency models for use in a specific application or for existing model technology to include in a new model to support a specific decision. In this case the Panel found it necessary to identify a number of similar models (i.e., atmospheric dispersion models or water quality models) and assess first the number of models available to choose from and, second, the consistency, transparency and comparability of the data for these similar models.

In answering CQ 7a, the Panel finds that the MKB has the potential to provide readily accessible information about models; however the amount and quality of information can be improved. For CQ 7b, the Panel recognizes that the information provided in the MKB is not highly detailed. As a result, sufficient level of detail about scales of data used and assumptions made during the formulation of any specific model in the MKB cannot be obtained from this tool alone. However, the MKB does allow for the initial identification of candidate models with links and references for obtaining further information.

For CQ 7c, the Panel agreed that the three models considered in this review were all good examples of successful models both in their regulatory role and in the way they are presented in the Knowledge Base. For the final Charge Question, the Panel was not satisfied with the current form of feedback mechanism for the Knowledge Base. More detailed observations, suggestions and recommendations follow.

7.2. Vision for the Knowledge Base

The issues surrounding which models to include in the MKB are not trivial; the Panel recognizes that this choice can have significant implications for the application of this tool in support of decision makers. The Panel is concerned that without a clear vision, the MKB may increase the burden on Regional and State offices by implying that a particular model is "endorsed" by the Agency. **The disclaimer on the main page of the MKB makes it clear that models in the Knowledge Base are not endorsed by the Agency but the Panel suggests that this disclaimer be clearly presented at the top of each "Model Report" page as well.**

Part of the Vision for the MKB should specify the role of this resource in the development or life cycle of models. More specifically, there needs to be a clear statement about what models are included in the Knowledge Base and what models or types of models are excluded (if any). This will require that the Agency provide a clear definition of "Regulatory Model," or else that it move away from this restrictive terminology towards a more inclusive title. The Panel recognizes that in addition to providing a repository or library of mature models that are actively used by the Agency, the MKB can also play an important role in the development of new models and the improvement of existing models. **For this reason, the Panel recommends that the Agency include models at all stages of their life cycle with a process for identifying to users those models that are new, actively being developed, currently used for decision-making and nearing retirement.**

An important aspect of any model repository from the perspective of a model developer or new model user is that it be as comprehensive as is feasible. In other words, users must be confident that when they use the MKB to identify an appropriate model for a task, it is likely that all relevant models have been considered. The draft MKB provides a good start but needs to continue to incorporate additional models used by the Agency. Many of the Agency's Offices, Programs, and Regions have developed their own clearing house for models; the Agency should make an effort to bring these existing data bases under the umbrella of the Knowledge Base. **The Panel recommends that the Agency identify these parallel Agency supported databases (e.g., the Support Center for Regulatory Air Models (SCRAM), the Center for Exposure Assessment Modeling (CEAM), etc.) and develop a plan to incorporate them into the MKB. If it is not feasible to incorporate these existing databases at this time, then the Panel suggests providing a current list of – and links to – these additional databases on the main page and the search page of the MKB.** In addition, there are ongoing efforts outside the Agency that are focused on developing common model documentation etiquette (Benz and Knorrenschild 1997) and a searchable web-based registry for existing models (Benz et al. 2001) that may provide useful insight during the continued development of the MKB.

The process of identifying and including existing models is clearly an important step to insure that the Knowledge Base is comprehensive. It is also important to continue to populate this MKB with new models as they emerge. **To accomplish this, the Panel recommends that the Agency incorporate new models into the Knowledge Base as part of their initial application within the Agency.** The information in the MKB for a given model is, or should be, part of the model development process so submitting this information as part of a model's initial application should not be an added burden to the model developers. Nevertheless, the Panel recognizes that it may be necessary for the Agency to provide additional incentive (positive or negative) as part of their plan to encourage what is currently a voluntary effort by modelers to put their model in the MKB.

To insure the continued improvement of what appears to be an extraordinarily valuable model information system, the Panel recommends that the Agency consider appointment of a Knowledge Base "System Librarian." This appointment might come from within the Agency or from an appropriately qualified contractor. The position would emphasize consistency in data collection and input of new information as well as system QA to improve information reliability with time, making the MKB a national resource for quality comparative information on both new and established models used in the regulation of the environment.

7.3. Quality Assurance and Quality Control

In addition to its role as an institutional memory, the MKB, in its current form, is clearly a tool designed and developed to support regulatory decisions by delivering useful information about prospective models for specific applications. The database itself is not unlike other "models" developed to support regulatory decisions. As noted in CQ6, the development of the MKB and the information provided in it should be subject to the same level of quality control and quality assurance that any Agency modeling effort is expected to include. **Therefore, in addition to the Vision Statement discussed earlier, the Panel recommends that the Agency provide a link on the main page of the Knowledge Base that takes the user to the Agency's plan for insuring the quality (integrity, utility and objectivity) of information provided.** At a minimum, this should contain the following elements:

a) <u>Problem specification that identifies the drivers for setting up the MKB</u> (i.e. reduce duplication of effort, improve networking, facilitate model development, satisfy training needs, etc.);

b) <u>Clear identification of the user community or "clients" for the MKB.</u> There was some ambiguity among the Regional representatives at the face-to-face meeting about whether the Knowledge Base satisfied their specific modeling needs and as a result there appeared to be a lack of "buy in" from the Regions;

c) <u>Identify specific performance criteria for the MKB information along with selection criteria for models in the database and identify who will be responsible for insuring that these criteria are met</u>; and

d) <u>If non-Agency models are eventually included in the MKB (see previous bullet on selection criteria) then the QA/QC plan should identify how these models will be treated or presented and who will absorb the burden of oversight for these models</u>.

The level of detail provided by each model should also be balanced. In the draft MKB, the details provided for models differ widely. An example of a model where information is very sparse is TRACI. Scientific detail is often just a statement of units used in the model (e.g., the SWIMODEL includes only the following statement under Scientific Detail "The model uses fixed units (S.I.)." and is missing Conceptual Basis all together). In other cases, it is not apparent that the sections include comparable information. For example, it is often difficult to distinguish between the Conceptual Basis, Scientific Detail and the Model Framework sections. **The Panel recommends that improved guidance be provided as part of the data entry sheet to insure that the correct type of information is input into each field.** This will also facilitate search functions by making sure those submitting the information realize what fields are searched.

It may be necessary to request a keyword list from the model developer. As an example of this last point, the Panel found that the CALPUFF model was not identified in the key word search using the phrase "air dispersion." Although "air" and "dispersion" are in the title or abstract, the phrase "air dispersion" is missing and as a result the model is not identified when the search is based on this common phrase. In another case, a search for "vapor intrusion" models (currently a timely topic) found no matches in the MKB. A search for "indoor air" models produced three matches, but none that appeared usable for the vapor-intrusion set of problems. This illustrates that there is still some significant work ahead to verify that the priority regulatory problems being addressed in Regional offices of EPA today are adequately considered in selecting candidate models to be included in the MKB.

7.4. Layout and Navigation of Knowledge Base

In addition to the recommendations already provided in Section 5, the Panel identified several pieces of information that should be elicited when a model is introduced into the Knowledge Base. In this section, the Panel provides observations about the current layout of the MKB and provides suggestions for where new information should be presented.

The current layout of the MKB is logical and generally easy to maneuver (with some exceptions noted later). The Panel found that much of the summary level material was readily accessible on the three main Report pages. The more detailed information is generally available through appropriate links. However, the Panel notes that in several cases, including the CALPUFF model, information is not provided for specific fields and rather than leave these fields blank, they are apparently removed from the Report. For example, the “Model Framework” and the “Model Evaluation” fields are often missing. The Panel recognizes that the Agency attempted to “cull information about models that broadly serve the needs of all users…” but once this minimum information is identified, it should be provided for all models. **The Panel recommends that if information is not provided for specific fields, those fields should be left blank rather than be removed from the Report. A blank field provides clear information about a model while a missing field is ambiguous.**

Overall, it was possible to use the MKB to obtain general information about the existence and availability of frequently used models and more detailed information about a specific model. But, really understanding how a given model works and what its specific strengths and weaknesses are would appear to require either going into the detailed documentation or contacting an actual user. Navigating the Knowledge Base was somewhat cumbersome, in that apparently different links go the same destination, links to critical information (e.g., model change bulletins) are obscure and the return link from exit disclaimer page forwards the user to the key word search page. In addition, several different pages (10 in the case of CALPUFF) needed to be accessed to gain a sense of model operation and capabilities. Perhaps accommodating the somewhat bewildering array of models and their varying characteristics is what's causing these navigational inefficiencies. **Nevertheless, the Panel recommends that the MKB system be reconfigured so as to streamline access to model information.**

7.5. Updating the Knowledge Base

The Panel recognizes that the MKB is a "living demonstration of the recommendations from the Guidance for Environmental Models." This suggests that the Knowledge Base will evolve and adapt to the specific needs of the user community. The comments above also support the premise that this will be an ongoing process of optimization. Optimizing the MKB will ultimately require an understanding of the user community and an active and transparent feedback mechanism. **To facilitate this, the Panel recommends that voluntary user profile and registration information be requested so that use profiles can be developed.** This information can also provide a mechanism for announcements to be distributed when necessary.

Improving the MKB and the models contained in it will ultimately depend on the quality of feedback from "external users" and the ability of new users to access this information. The Knowledge Base is currently limited to a single contact and does not provide any suggested format for comments nor does it provide for open dialogue and discussion of modeling experience. This seriously limits the Agency's ability to adapt the MKB and improve its utility. This lack of an open forum also limits the model developers from gaining experience from model users and it limits the ability of new modelers to learn about specific experience and application of a particular model. **The Panel recognizes the challenges associated with hosting an open forum on an Agency web site but recommends that the Agency reconsider including a transparent user feedback mechanism that will facilitate an open dialogue for the models in the MKB.**

7.6. The Role of the Knowledge Base as a "Model Selection Tool"

The Panel is not entirely convinced about the utility of a model selection tool or expert system that accesses the MKB to facilitate model selection. However, the Panel suggests that if such a tool is developed for application at the EPA Regions, labs and states, then the effort should be considered "model development" and as such should clearly follow the guiding principles in the Guidance on Environmental Models.

If such a model selection tool is developed, it will likely be used early in the life of a project so identifying specific needs and valuing these specific needs in a way that would facilitate a model ranking would be difficult to achieve. **Therefore the Panel recommends that any tool developed by the Agency to facilitate model selection based on the Knowledge Base should simply present the models in a comparative matrix in the form of a side-by-side comparison table like one would see in the car sales industry.**

Appendix C provides more detailed information about Panel members' experiences in accessing and using specific models.

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Appendix A - Enhancements to the Glossary

Consensus on a common nomenclature is a key requirement for implementing a consistent Agency-wide approach for environmental model development, use and quality assurance. The Glossary in the draft document is a preliminary step towards this goal. However, several aspects of the Glossary would benefit from additional technical and editorial attention:

1) The reader is likely to be frustrated when looking up underlined terms from the text when the terms are not listed in the Glossary in the same form that they appear in the text, e.g.: Spatial and temporal domain (p. 9; listed under Domain in glossary), code verification (p. 12), model evaluation (p. 16), model validation (pp. 16 and 43; also appears on p. 30 in the definition for corroboration), integrity (p. 16), proprietary models (p. 23).

2) Several terms are defined in the Glossary slightly differently from their definitions in the text; it is suggested that the definition be the same in both locations. Module (Box 2 on p. 37); Terms from Box 3: Applicability and Utility, Clarity and Completeness, Evaluation and Review, Objectivity, Uncertainty and Variability. Application Niche Uncertainty (p. 21).

3) Several terms are not in alphabetical order in the Glossary: Expert Elicitation, False Negatives, Forms (models), Model, Parameter Uncertainty, Quality,Variability.

4) Several additional terms should be added to the Glossary (and underlined in the text) and either defined at that location, or else cross-referenced to another existing term in the Glossary for the definition (as has been done for "Parameter Uncertainty”): Acceptance Criteria (Box 3), Bayesian view (p. 56), Beta test, bootstrap sampling (p. 48), Bug (computer), Configuration tests, Data, Data Acceptance Criteria (p. 43),

Empirical data (p. 21 and 45), Errors, hyperplane (p. 51), Integration Tests (App B), Monte Carlo analysis (p. 53), Normal Distribution (p. 45), Paradigm (App C), Parameterize, Peer Review, Platform, Post-processing (model output), Qualifiers (for analytical data) (Box 5 on p. 43), Quality Assurance, Regimes (p. 48), Representativeness (p. 20; Box 5 on p. 43), structural error (p. 21), Type I error (p. 45), Type II error (p.45), User interface (p. 33, used in definition for Object-Oriented Platform).

5) Cross-references to more specific terms in the Glossary should be added to the definitions for generic terms, e.g.:
   a) Decision errors: See also False Negatives, False Positives,
   b) Errors: See also Accuracy, Bias, Data Uncertainty, Confounding Errors, Data Uncertainty, False Negatives, False Positives, Measurement Errors, Model Framework Uncertainty, Noise, Uncertainty, Uncertainty Analysis, Variability, and
   c) Model: See also Conceptual Model, Deterministic Model, Empirical Model, Mechanistic Model, Screening Model, Simulation Model, Statistical Model, Stochastic Model.

6. The definition of the term "model complexity" should be expanded to emphasize process issues (model spatial, temporal, and kinetic resolution) first. The mathematical, numerical, and computational aspects of complexity should take assume a secondary posture.

7. In addition to the Glossary, the Agency should consider adding a <u>List of Acronyms</u> to guide the reader through this multi-disciplinary, multi-organizational Draft Guidance. A few candidate acronyms for inclusion in this list would be: AA-ship, ANSI, ASQC,

ASTM, CREM, DQO, FACA, IQG, NCSU, NMSE, NRC, OAT, OMB, PDF, TMDL, as well as the numerous EPA offices.

Appendix B - The CREM Models Knowledge Base Data Entry Sheet

Instructions

1. Please complete this data entry sheet for each model that you want to be included in the CREM Models Knowledge Base. You may use as much space as necessary.

2. You are encouraged to include URLs to other sources of information, graphics, and other pertinent documents (in PDF or other formats).

3. The data entry sheet for the IPM model is provided as an example.

4. Any questions? Need assistance? Please contact Neil Stiber (202-564-1573).

(A) General Information	
1. Model Name:	
2. Model Overview / Abstract:	
3. Contact Information (name, affiliation, e-mail, phone #):	
4. Model's Home Page:	
(B) User Information	
1. Technical Requirements:	
a) Computer Hardware:	
b) Operating Systems:	
c) Programming Languages:	
d) Other Req'ts and Features:	
2. Download Info (with URL):	
3. Using the Model:	
a) Basic Model Inputs:	

b) Basic Model Outputs:	
c) User's Guide:	
d) Other User Documents:	
(C) Model Science	
1. Conceptual Basis of the Model:	
2. Scientific Detail for the Model:	
3. Model Framework (equations and/or algorithms):	
4. Model Evaluation (verification (code), corroboration (model), sensitivity analysis, uncertainty analysis):	

(D) Model Criteria

Please use the shaded boxes on the left to select all criteria that are relevant to the model. Criteria should be selected based on an appropriate level of generality / specificity. Please note that selection of specific criteria (e.g., "Pollutant Type"); necessarily includes the more general (e.g., "Releases to the Environment") but, not the more specific (e.g., "Physical").

	Regulations
	Clean Air Act (CAA)
	Clean Water Act (CWA)
	Safe Drinking Water Act (SDWA)
	Resource Conservation and Recovery Act (RCRA)
	Comprehensive Environmental Response, Compensation, & Liability Act (CERCLA)
	Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
	Toxic Substances Control Act (TSCA)
	Releases to the Environment
	Pollutant Type
	Physical (e.g., radiation, heat, particles, fibers, noise)
	Chemical (e.g., organic, inorganic, toxics)
	Biological (e.g., microbial)
	Source Type
	Point source (e.g., tank, spill, stack, discharge pipe)
	Area source (e.g., spray, fertilizer, lagoon, holding area)
	Mobile source (e.g., automobiles, trains, ships, airplanes)
	Ambient Conditions
	Media
	Ground (e.g., soil, sediment)
	Water (e.g., surface water, ground water)
	Air
	Ecosystem
	Processes
	Transport (e.g., advection, bulk, dispersion, diffusion)
	Transformation (e.g., chemical reaction, partitioning, biodegradation)

	Accumulation (e.g., deposition, sedimentation)
	Biogeochemical (e.g., cycling, growth, consumer-resource)
	Exposure or Uptake
	Exposure Characterization
	Location
	Frequency and Duration
	Pathway (e.g., inhalation, digestion, dermal, injection)
	Body Burden – Dose (e.g., phamacokinetics, retention, transformation)
	Changes in Human Health or Ecology
	Human Health Indicators
	Mortality
	Chronic and Acute Diseases
	Ecological Indicators
	Population Changes
	Acute & Chronic Disease Occurrence
	Land Use Change

Appendix C - Panel Members Experiences Using the MKB

This appendix summarizes comments related to the form and function of the Knowledge Base with specific emphasis on models selected to facilitate the review and response for Charge Question (CQ) 7. Because the following narrative is meant to convey the individual reviewers experience with the MKB during the review, the narrative has not been heavily edited.

C-1 CALPUFF (The Illustrative Air Model):

The CALPUFF example evaluation starts from the "Models Knowledge Base" page, and then goes to the listing of available models, and from that to the CALPUFF model report. With respect to CQ **7(a),** if the user wasn't going to a specific model, it would be hard to decide, using this list alone, how to choose from among the several seemingly air-related models listed (however, the keyword search capability is helpful for this). A model overview on the "general information" page provides information that addresses, in part, CQ **7(b).** Going to the "user information" page gives information on downloading and the availability of user's guides. Here the heading "Using the Model" is slightly misleading in that it implies information on how the model is used to make decisions but is actually about how a modeler would run the model. This section also provides no citations or links as to application of model results in actual decision making. Although the "Recommendations for Regulatory Use" section is informative, it also provides no citations or links as to how model results have faired in actual decision-making. The "Model Evaluation" section is clearly about evaluation of the model as a model and not as a decision support tool.

The MKB does provide sufficient information to accomplish goal 7a for the CALPUFF model in that it allows users of the data base to locate candidate models which might serve their purpose. However, it should not be considered as providing a substitute (e.g., in summary report form) of the detailed information that has to be retrieved from the open literature in order to compare potentially relevant models for an application. It would be impractical for the MKB to provide the level of information necessary for users to determine which models are suitable for every application, but it can certainly help eliminate duplication by providing a limited number of candidates to consider. Evaluating these candidate models requires consistency in the presentation of information.

The MKB cannot reasonably be expected to provide sufficient detail to fully address a model users/developer's questions about CALPUF. However, it can and should answer basic questions such as "at what temporal and spatial scales has the model been shown to operate successfully?" and (for air models in the GAQM) "at what scales are these models considered to be preferred or acceptable alternatives to preferred models?" This information should be sufficient to guide users of the MKB to ask the right questions, but probably cannot provide complete answers, since understanding the "endogenous assumptions made during model formulation" will require detailed understanding of the model algorithms beyond its scope.

The models presently in the MKB differ widely in terms of ranges, attributes, objectives etc. The completeness/focus of the "model report" information also varies widely relative to the amount of information provided. For example, under User Information, essentially all that is provided for CALPUFF is links to the SCRAM and to the developer's web site, but for some other vendor-supplied models, summary information is provided in the MKB itself (plus appropriate links). Because vendors may provide information on models as they see fit, it would be beneficial to have at least a summary of basic information about each model in the MKB. As indicated in the Panels' Report, this information should include computational requirements (including operating systems supported and requirements for other software), descriptions of input data requirements, and descriptions of model output. Additional useful information could include some examples where the model was successfully applied, along with references and contact information to facilitate further research into the suitability of models for specific applications.

As another example of the need for consistency, the CALPUFF site under the "user information" section, the link to "Technical Requirements" is missing. To facilitate identification of all candidate models for a specific task, each model should have the same major sections. Similarly, the Framework section on the Model Science page is missing for CALPUFF (as well as for AquaTox). Even if sections are left blank, they should be included for every model to facilitate use of the MKB. The top page of CALPUFF model developer's website provides little information about the science of the model but does nicely summarize model updates, provides links to its regulatory status, a download, and training opportunities. The "regulatory status" page provides information similar to that found on the EPA "model science" page but goes further by offering links to notices and reports on regulatory use. This also highlights the need for some support by the Agency to synthesize information provided by the model developer in order to provide a consistent format and level of detail.

Navigating the CALPUFF pages was somewhat awkward. The Environmental Indicators search feature was the least useful since it presupposes knowledge of how the Agency defines and uses such indicators. One of the download links from the "user information" page leads to EPA's SCRAM website, as does a similar link for "model homepage" on the "general information" page. The SCRAM website is apparently the only point at which it is possible to access the critical "Model Change Bulletin" and "Model Status" records, which are somewhat obscurely included only as "Notes" in smaller font. There appears to be considerable overlap in these two sets of information and the question arises why they couldn't be combined in one more accessible location (e.g., on the "user information" page). The link to the NTIS site is probably necessary but models without online documentation would appear to be at a disadvantage. Getting to CALPUFF on the SCRAM website from either the "general information" or "user information" pages provides one with a link to the model developer's website, who is a contractor and not the EPA. A link directly to this website is also on the "user information" page. Thus, there are three apparently different links on two different pages all leading to the same destination, a non-EPA website. This seems unnecessarily convoluted. It is not entirely clear until this point that genuinely useful information on the model resides with a contractor and not with the Agency.

Something seemed to be wrong in the keyword search feature on the MKB primary panel, since entering "air dispersion" produced only three results, all related to the RAIMI. This search should produce several hits including CALPUFF. The Panel recognizes that the search is only performed on the title and abstract so if the word or phrase is missing from this field it will not be found. In CALPUFF, the abstract does not include the word "air" so it is not picked up by searching for "air dispersion." The "browse for models by selecting for environmental indicators" seems to have no search criterion which locates CALPUFF either. Also, after inadvertently selecting "Exit Disclaimer" on the CALPUFF User Information page, the "Return to Previous Page" takes the user to the "Browse to Knowledge Base" page rather than the previous page.

On the CALPUFF model developer's website, a reference is made to the Guideline on Air Quality Models (GAQM), while in the MKB, there is a reference to "Appendix W." In fact, both refer to the same document. The MKB should be clear that Appendix W to 40 CFR Part 51 and the GAQM are the same. Both the Model Knowledge Base and the model developer's web sites should provide links to the GAQM.

The MKB includes many highly successful models (including CALPUFF), but it is not clear how users will be able to determine for themselves which ones are "successful." Clearly models "preferred" in the GAQM qualify, but a similar gold standard may not exist for other media. Other GAQM models may be assumed to have achieved some measure of "success." A list of the applications of a model could be useful in providing a measure of its success. To allow one to judge the level of success of a particular model, the summary report should provide a very simple summary of the "applicability range" of the model. For example the summary report states that "CALPUFF" is intended for use on scales from tens of meters from a source to hundreds of kilometers" but does not mention the fact that the minimum temporal resolution of the model (hourly averages) restricts its applicability to a simulation range that does not include important short-term phenomena (e.g., emergency events such as accidental spills), dispersion of heavy gases, etc.

As indicated in the Panel's report, especially important information that should be included in the MKB are i) all input/output formats, ii) all software tools (public domain and proprietary – as well as potential substitutes) that are needed in order to fully utilize the model's capabilities, iii) available databases of inputs (potentially outputs from other models), and iv) past evaluations (especially cross-evaluation) studies involving the model(s) of concern. The MKB provides the opportunity to turn abstract discussions in the Guidance into specific examples; however, in order to achieve this, more detailed and consistent information needs to be included in the MKB.

The role of the EPA as the "model contact" is not clear for the feedback forum. The appropriate or desired role of the model contact as either an internal (Agency) or external (public) interface for the model should be made clear at this stage of the development of the MKB. It would also seem that a more direct link to the actual developer and maintainer of the model would be helpful. The MKB appears to have no formal feedback mechanism other than contacting Mr. Pasky Pascual. Feedback from model users could be extremely valuable to others who have specific modeling needs. The information would help users answer the charge questions posed in 7a-c. The MKB could solicit comments from users of the models, and post these comments on a bulletin board. Postings should allow for anonymity, as some model users might not want to be identified personally as users of the models – for example it is not unusual for busy modelers to get phone calls from graduate students wanting help running complex environmental models for thesis projects.

C-2 The Integrated Planning Model (IPM – The Illustrative Economic Model)

The write up on IPM in the MKB is very thorough. It is clear, concise and helpful as a first description of what this model contains and what it is used for. It turns out that almost all of the write-up is a verbatim cut and paste from the IPM Model Documentation. This is sufficient as long as the appropriate items are covered at sufficient depth. However, in examining the IPM Model Documentation, page 2-5 begins a section on Key Methodological Features (e.g., details of how the load duration curve is specified and information on how the dispatch order is determined) that could be simplified and incorporated into the MKB to bring the reader one level further down in detail. Thus, to maintain consistency in the level of detail presented in the MKB, it may be necessary for existing documentation to be re-written with a consistent format across all models. It is recognized that this would likely require a scientific editor/webmaster dedicated to the task of working with the model developer to prepare the documentation for upload onto the MKB.

The Panel recognizes that the MKB alone is unlikely to provide sufficient information for new model developers who may require a detailed understanding of potentially competing models. This type of information can only be obtained, if at all, from model documentation. The IPM site, which can be accessed from the MKB, does contain links to such detailed documentation. In this sense new modelers may benefit. On the other hand an internet search or a search of the EPA's website would immediately bring up such documentation without the need for the MKB. New developers would be particularly keen on knowing the IPM's limitations and assumptions, none of which seems to be available. IPM in particular is extremely well entrenched in the Air Office and would be, therefore, unlikely to attract "new model developers."

The level of detail on "endogenous assumptions" for a given model is dependent on the information provided by the model developer, so at some level this may be out of the realm or control of the developers of the MKB. Evaluating the utility in contrast to other models requires first that competing models be identified through the MKB, and second that the MKB provide enough information at a comparable level of detail so that appropriate choices on which model to use can be made. A high spatially resolved model is expected to be more accurate than one of lower resolution, but choices about resolution always involve tradeoffs, such as in model complexity, data availability, model flexibility, and the types of questions a model is designed to answer. The charge question does not encourage this kind of thinking (although earlier questions may) and the database is silent on providing information to aid in this type of thinking as well.

For IPM, spatial resolution is clearly given – all 48 states plus DC are covered along with a number of coal producing regions that are identified. Temporal resolution is less clear. The time step for the model is not explicit but the forecasting horizon of the model is clear. Exogenous assumptions are not fully provided directly on the MKB model page, but model documentation accessed through links would surely provide this information for this model. There is a list of key assumptions (e.g., perfect foresight, pure competition) in the IPM Model Documentation document; this information should be provided in the MKB. Again, as noted earlier, modelers should be asked to provide a write-up for the MKB of significant limitations of their models in terms of simplifications, strong assumptions, and factors that have been ignored and/or are outside the scope.

The Panel agrees that the IPM model is a good example of a "successful" model. A forum for feedback on model uses outside Agency applications and a means of collecting external suggestions for updating/improving model structure are currently inadequate.

C-3 Aquatox (The Illustrative Water Quality Model)

A new model developer would find the documentation and descriptive material on the technical and theoretical aspects of AQUATOX very helpful in elimination of duplication. Processes in the model are well documented in the MKB and the associated model documentation provided on the AQUATOX web site.

The technical documentation of Release 2.0 is reasonably thorough with regard to process documentation and assumptions inherent in the model. However, the format of the report does not follow the recommended elements for model documentation given in the Draft Guidance. The Panel would prefer to see a separate "Model Development" chapter that includes a conceptual model, a complete disclosure of all model assumptions and resulting caveats, and data used to convert the conceptual model to a mathematical model. Release 2.0 does specify that it can only be used in a non-dimensional or one-dimensional mode and does discuss the temporal scales of use. There are certainly limitations to the model use imposed by these assumptions; the document does discuss these.

This model has not had a long history of application in its current form, although it does have a long history of application of previous incarnations of the model (e.g., as CLEAN or CLEANER or PEST). The user manual presents several examples of applications of the model; however, only one of them (Onondaga Lake) shows system data that allows the user to assess the success of these applications. On the web site, model "validation" examples are offered in an EPA report published in 2000 that includes Onondaga Lake, PCBs in Lake Ontario, and agricultural runoff in the Coralville Reservoir. It does appear that these evaluation exercises compare AQUATOX with data and previous models for these systems, which is good. There is no discussion of regulatory use of the model. The documentation does make the point that this is a multi-stressor, multi-response model.

Finally, the model web site provides an opportunity to become a registered user; however, it is not clear that this is the portal to provide feedback to the Agency on outside application experience or suggestions.

C-4 Other Models

As noted in the Panel's report, it was necessary to evaluate other models in the MKB in order to assess the level and consistency of detail and ease of use. The following comments are general observations from this survey.

The Panel found that figures and diagrams were particularly helpful in the section describing the model conceptual basis as used in the IPM. The information provided for a number of the models is not necessarily in line with the definition of "Conceptual basis" as described in the Guidance. The descriptions range in detail from providing a statement of what the model does to what inputs are required but not always clear on what the conceptual basis is (i.e., is it mechanistic, or empirical, or something in between). The BLP model has only two of the four sections in the model use section. There also appears to be some confusion between "Scientific Basis" and "Model Framework," which is illustrated by the similar level of information provided in the Scientific Basis section for CALPUFF and the Model Framework section of the IPM. With the IPM it appears that the text was pasted into the sections on conceptual basis, and that the framework section was used to capture overflow text. This reconstruction suggests confusion in populating the MKB system, either on the part of the person who filled out the original Data Entry Sheet or the person who uploaded this information from the data sheet into the MKB system.

It would be useful if the web page on "User Information" provided an indication of the level of user expertise required to apply the model. For example, the IPM states that "The model's core LP code is run by ICF Consulting…" while at the other extreme, the THERdbASE states that "User needs only moderate level of technical education and/or modeling experience." This type of information is valuable for users planning to actually apply the models beyond just learning what is available.

The Panel found that the level of detail provided in the MKB is very different across models. An example of a model that is very sparse is TRACI. Scientific detail is often just a statement of units used in the model (e.g., the SWIMODEL includes only the following statement under Scientific Detail "The model uses fixed units (S.I.)," and is missing Conceptual Basis all together). The NWPCAM report is missing the model evaluation section. This speaks to the issue of quality control across the MKB. If the Agency is going to take responsibility for the quality of information provided on these pages, then there will need to be some oversight provided to the various people inputting data in order to get an acceptable level of consistency for the information provided. Or, as indicated earlier, there may be a need for a dedicated Scientific Editor.

The Panel has recommended that the MKB include more detail on model version. A good example of a version tracking matrix or table is given on the PRIZM version index page that is found by following the links to the model web site that goes through the EPA Center for Exposure Assessment Modeling (CEAM) site (http://www.epa.gov/ceampubl/products.htm) by selecting the model from the menu.

It is important that the information in the MKB be kept current. It would be helpful for keeping the information up to date if an annual automated message was sent to individuals listed as the model contacts requesting updates or reviews of the material on the MKB. As an incentive, this could be accompanied with a report on the number of accesses that were made to the specific model.

The user community for the MKB may provide a very effective policing mechanism to maintain model quality, especially when money is at stake. This provides a clear opportunity and incentive for improving the models it contains. However, this requires a more transparent feedback mechanism, which is currently lacking.

Once this resource is developed, the Panel recognizes that the MKB may be a good candidate for technology transfer over the long-term. MKB has value; maintaining current information and continuing to make improvements may be better left to the private sector, possibly in the form of a non-profit organization.

Appendix D - Description of the SAB Process

D-1 Request for EPA Science Advisory Board (SAB) Review

In a memo dated October 4, 2001, Dr. Gary J. Foley, Director of the National Exposure Research Laboratory, and Chair of the Council for Regulatory Environmental Modeling (CREM), requested to Dr. Donald G. Barnes, the Director of the Science Advisory Board Staff Office, that the SAB review this topical area. The title of the memo is *"Request for Science Advisory Board Review of a draft outline of a proposed document entitled "Guidance on Recommended Practices in Environmental Modeling."* In October, 2001 a draft outline was provided to Dr. Barnes. The charge questions listed in that memo were mostly focused on policy and procedural items, and the SAB Staff Office declined to engage further, recommending that the CREM focus more on technical and science issues.

In a memo dated February 7, 2003, EPA Administrator Christine Todd Whitman designated Dr. Paul Gilman as the EPA Science Advisor, and also asked him to revitalize the CREM, and asked that the CREM accelerate its efforts to ensure that the necessary policy guidance and support systems are in place for use by all model users across EPA. Toward that end, Administrator Whitman asked that the CREM, working with Dr. Gilman as the EPA Science Advisor, work with the Science Policy Council to accomplish a number of items in 2003, including establishing the following:

a) Make publicly accessible an inventory of EPA's most frequently used models, which will include information on a model's use, development, validation, and quality assessment;

b) Provide guidance for the development, assessment, and use of environmental models;

c) Sponsor a series of workshops in the regions to engage a broader community of model users and stakeholders regarding model use in environmental decision-making;

d) Initiate immediately a collaborative effort with the National Academy of Sciences (NAS) to develop a report recommending best principles and practices in using environmental and human health models for decision-making; and

e) Establish a stakeholder group of environmental model users outside EPA to interact with CREM and the NAS for the benefit of the broader community of model users.

Administrator Whitman recognized that the above are not easy tasks, but that by undertaking them, ...” *the Agency will maintain their leadership role among federal agencies in ensuring that strong science informs policy-making and in facilitating environmental protection in the face of evolving science.*”

D- 2 Panel Review Procedures

D-2-1 Request for Review and Acceptance

In February, 2003, the EPA Administrator had appointed the AA for ORD as the EPA Science Advisor and requested him to revitalize the CREM. She also asked that the CREM accelerate its efforts to ensure that the necessary policy guidance and support systems are in place for use by all model users across EPA. Toward that end, Administrator Whitman asked that the CREM, working with Dr. Gilman as the EPA Science Advisor and with the Science Policy Council to accomplish a number of items in 2003, including the SAB review. After considering all requests for 2003 the Science Advisory Board (SAB) determined that the review should be conducted by a specialized panel. The Director of the SAB Staff Office, in consultation with the Chairman of the SAB, selected SAB member Dr. Thomas L. Theis of the Institute for Science and Policy at the University of Illinois in Chicago, as chair of the Regulatory Environmental Modeling (REM) Guidance Review Panel.

a) Panel Formation

The Panel (Regulatory Environmental Modeling (REM) Guidance Review Panel) was formed in accordance with the principles set out in the 2002 commentary of the SAB, *Panel Formation Process: Immediate Steps to Improve Policies and Procedures: An SAB Commentary* (U.S. EPA SAB. 2002). A notice offering the public the opportunity to nominate qualified individuals for service on the Panel was published in the *Federal Register* on August 6, 2003 (68 FR 46602). Soliciting nominations for Panel membership and can be found on the SAB Web site at: http://www.epa.gov/sab. Sixty-seven individuals were considered for membership on the Panel. On the basis of candidates' qualifications, interest, and availability, the SAB Staff Office made the decision to put 35 candidates on the "short list" for the Panel. On August 19, 2004 and on October 12, 2004, the SAB Staff Office posted notices on the SAB Web site inviting public comments on the prospective candidates for the Panel.

The SAB Staff Office Director — in consultation with SAB Staff (including the Designated Federal Officer (DFO), the Acting SAB Ethics Advisor), and the Chair of the Executive Committee — selected the final Panel. Selection criteria included: excellent qualifications in terms of scientific and technical expertise; the need to maintain a balance with respect to qualifying expertise, background and perspectives; willingness to serve and availability to meet during the proposed time periods; and the candidate's prior involvement with the topic under consideration. The final Panel includes persons with expertise in one or more of the following areas:

a. Hazardous Waste,
b. Atmospheric Transport,
c. Transformations and Removal,
d. Groundwater Hydrology,

e. Water Quality,
f. Indoor Air,
g. Multi-Media Environmental Fate and Transport,
h. Environmental Management,
i. Terrestrial and Aquatic Ecology,
j. Epidemiology,
k. Public Health,
l. Sensitivity Analysis,
m. Uncertainty Analysis,
n. Exposure and Risk Assessment,
o. Environmental Law,
p. Decision Analysis,
q. Economics,
r. Computer Sciences,
s. Spatial Modeling,
t. Model Documentation,
u. Nomenclature for Environmental Models,
v. Statistics, and
w. Information Quality Guidelines, Data Quality and Quality Assurance Procedures.

The Panel members, in addition to having new persons to serve, also include individuals who are experienced SAB consultants familiar with the Agency. The final panel determination memo was signed on October 14, 2004 and posted prior to the January 21, 2005 conference call meeting of the Panel.

b) Panel Process and Review Documents

The Panel first met via conference call on January 21, 2005. The purpose of this initial public conference call meeting was to provide background information for the Panelists on the issues in preparation for the advisory activity. The Panelists a) discussed the charge, review and background materials provided to the Panel, b) discussed specific charge assignments for the Panelists, and c) advised the Agency CREM participants of any specific points that need clarification for the February 7, 8, and 9, 2005 meeting.

The February 7, 8, and 9, 2005 face-to-face meeting was held in Washington, DC. This also was a public meeting, and as in the January 21, 2005 teleconference call, an opportunity was provided for public comments pursuant to and consistent with the requirements of the Federal Advisory Committee Act (FACA. Public Law 92-463). All panelists were present at the February 7, 8, and 9, 2005 meeting. Additional public conference calls were held on March 28, June 16, August 17, and October 12, 2005 to prepare a consensus draft report and complete edits complete to the draft report by the Panel.

Will do a brief summary of the Board's Quality Review process when that is complete - - - - KJK)

APPENDIX E -BIOSKETCHES

OF THE

REGULATORY ENVIRONMENTAL MODELING (REM) GUIDANCE REVIEW PANEL OF THE

ENVIRONMENTAL PROTECTION AGENCY (EPA) SCIENCE ADVISORY BOARD (SAB)

The EPA Science Advisory Board (SAB) Staff Office has formed the SAB Regulatory Environmental Modeling (REM) Guidance Review Panel. Nominations for technical experts to serve on this SAB Panel were requested in the Federal Register (68FR 46602) on August 6, 2003.

Dr. Linfield C. Brown:

Dr. Linfield C. Brown is Professor and former Chairman of the Civil and Environmental Engineering Department at Tufts. Professor Brown earned his Bachelor of Science Degree in Civil Engineering (BSCE) and MS from Tufts and his Ph.D. in Sanitary Engineering at the University of Wisconsin-Madison. His research has covered a broad range of topics in sampling strategies, flow equalization, oxygen transfer, and most recently, uncertainty analysis in water quality modeling, multi response parameter estimation, and the use of genetic algorithms for model calibration. Dr. Brown has served as consultant to both industry and government. As a research engineer with the National Council for Air and Stream Improvement (NCASI), he developed their national program in mathematical water quality modeling. While on sabbatical leave at the US EPA Center for Exposure Assessment Modeling (CEAM), he designed and implemented a computational framework for incorporating uncertainty analysis into the water quality model, QUAL2E.

Dr. Brown is the author of over 50 technical papers and reports covering the fields of environmental engineering and statistics and has offered over two dozen workshops in the US, Spain, Poland, England, and Hungary on water quality modeling and control. He is co-author of the book Statistics for Environmental Engineers, which describes the practical application of statistics to a variety of environmental engineering problems. He founded and was academic director of an innovative multi-disciplinary Masters program in Hazardous Materials Management, and initiated a similar program in Environmental Science and Management for mid-career professionals, targeted specifically for women and minorities. He received from Tufts, the prestigious Lillian Liebner Award for excellence in teaching and advising. Dr. Brown currently serves as consultant to the Environmental Models Sub-committee of the USEPA Science Advisory Board and is director of the Tufts ABET accredited BSEvE program. In addition to his university support, Dr. Brown has received funding from the New England Water Pollution Control Commission which, in turn, receives funding from EPA Region I.

<u>Dr. Joseph V. DePinto:</u>

Dr. DePinto is currently a Senior Scientist at Limno-Tech, Inc.(LTI), an environmental consulting company specializing in the development and application of water quality and ecosystem models for addressing a myriad of problems in aquatic ecosystems. He joined LTI in June, 2000 after spending 27 years in academia, including 10 years as Director of the great lakes program at the University of Buffalo. Dr. DePinto received his Ph.D. in Environmental Engineering in 1975 form the University of Notre Dame. During his professional career, Dr. DePinto has directed projects involving the development and application of models applied to a wide range of topics, including nutrient-eutrophication, toxic chemical exposure analysis, contaminated sediment analysis and remediation, aquatic ecosystem trophic structure and functioning, and watershed management. His studies have led to over 100 publications and the direction of more than 45 master's theses and 12 Ph.D. dissertations.

Dr DePinto's recent modeling research projects (with funding sources in parentheses), both prior to and subsequent to joining LTI, that are relevant to the subject

SAB panel include: development and application of an integrated exposure model for PCBs in Green Bay, Lake Michigan (EPA-ORC); development and application of sediment and contaminant fate and transport models to assess and evaluate remediation of contaminated sediments in several river systems, including the Buffalo River (EPA-Great lakes National Program Office (GLNPO)), St. Clair River (Ontario Ministry of Environment), Lower Fox River (Fox River Group), Kalamazoo River (Kalamazoo River Study), Niagara River, and Hudson River (EPA-Region 2 through TAMS); led a team of scientists and engineers at the University at Buffalo in the development of a Geographically-based Watershed Analysis and Modeling System (GEO-WAMS), a Modeling Support System that coupled a Geographic Information System (ARC-INFO) with existing and newly developed watershed and water quality models (EPA-ORD); led the development and application of a trophic transfer model for lake Ontario intended to evaluate the role of fish management practices relative to phosphorus levels in top predator fish production in that system (New York Sea Grant); was the technical director of a project to develop a model for dissolved oxygen in the Black River (OH) system to quantitatively assess the cause of low dissolved oxygen in the deep navigational portion of the river, which exhibited two-dimensional, stratified flow conditions because of Lake Erie seiche effects; co-investigator on a project to model the flux of PCBs and other organic chemicals across the air-water interface of lake Michigan (EPA-GLNPO); and led the development of a linked fine-scale hydrodynamic model (POM) with a toxic chemical (hydrophobic organic chemicals and mercury) transport, fate, and bioaccumulation model (LOTOX2) for support of the Lake Ontario Lake-wide Management Planning (LaMP) process and a PCB (Total Maximum Daily Loading) TMDL for Lake Ontario (EPA-Region 2cand EPA-GLNPO through the University at Buffalo).

Dr. DePinto has been a leader in the development and application of *aquatic ecosystem models* aimed at providing a quantitative understanding of the impacts of multiple stressors acting in concert on aquatic systems to produce multiple response endpoints. This new paradigm of modeling allows simultaneous consideration of several management areas, such as nutrient load control, toxic chemical exposure, fish harvesting/stocking practices, aquatic nuisance species invasions, and water use and resource management. Probably the best example of this work is the development of the Saginaw Bay Aquatic Ecosystem (SAGEM), funded by EPA-ORD and EPA-GLNPO. SAGEM is a deterministic process model designed to examine the ecological processes of Saginaw Bay, Lake Huron to the invasion of zebra mussels (*Dreissena polymorpha*). In particular, the model was developed to illustrate the processes governing the effect of zedra mussels on nutrient cycling and phytoplankton production and speciation, on cycling and bioaccumulation of PCBs, and on the impact of zebra mussels on the relative contribution of phytoplankton and benthic algae to primary production in the system. Recently, Dr. DePinto has been working on the development of linked modeling frameworks that allow the evaluation of water use or levels/flow regulation on a range of ecological endpoints. He is directing a project, funded by the International Joint Commission through the USACE-Institute for Water resources, with the objective of developing an Integrated Ecological Response Model (IERM) that quantitatively relates water level/flow regulation in the Lake Ontario/St. Lawrence River system to important ecological performance indicators such as wetland plant diversity and wildlife abundance. In a similar vein, Dr. DePinto has led the development of a prototype linked model framework (GLECO) to relate water withdrawals/diversions to ecological responses in river-based watersheds in the great Lakes basin (funded by the great Lakes Protection Fund).

Dr. DePinto has also had considerable experience in evaluating models and providing guidance for the use of models in the TMDL process. He is the lead author on a peer-reviewed paper in press that presents modeling principles for TMDL modeling practitioners. He has reviewed or is in the process of reviewing several model development and application programs for TMDLs, including a review of a Hg TMDL pilot study in the Everglades for the State of Florida; modeling consulting to the Delaware River Basin Commission in their effort to develop a PCB TMDL model (linked hydrodynamic and PCB mass balance) for the Delaware River/Estuary; serving on a modeling guidance panel for the application of the WARMF model for use in the development of a phosphorus-chlorophyll a TMDL for the Catawba River system in

South Carolina; and is an invited member of the Model Evaluation Group (MEG) for the Contaminant Assessment and Reduction Project (CARP) of the New York/New Jersey Harbor Estuary Program (supported by the Hudson River Foundation). Finally, Dr. DePinto has served on many councils and committees to develop research needs for aquatic system management and modeling. For example, he is currently a member of the International Joint Commission, Council of Great Lakes Research Managers, which has as one of its missions the identification of research needs in Great Lakes to support the Great Lakes Water Quality Agreement.

Dr. Panos Georgopoulos:

Dr. Georgopoulos is Professor of Environmental and Occupational Medicine at the University of Medicine and Dentistry of NJ - Robert Wood Johnson Medical School. He is also a member of the Graduate Faculties of Chemical and Biochemical Engineering and of Environmental Sciences at Rutgers University, and of the Environmental and Occupational Health Sciences Institute (EOHSI), which is a joint project of UMDNJ-RWJMS and Rutgers. Dr. Georgopoulos received his M.S. and Ph.D. Degrees in Chemical Engineering from the California Institute of Technology (Caltech) and his Dipl. Ing. Degree from the National Technical University of Athens. At EOHSI he established and directs the Computational Chemodynamics Laboratory (CCL, www.ccl.rutgers.edu), a state-of-the-art facility for Informatics and Modeling of Complex Environmental and Biological Systems. Furthermore, he directs the State-funded Consortium for Risk Evaluation with Stakeholder Participation (CRESP); and he co-directs the USEPA-funded Center for Exposure and Risk Modeling (CERM), all at EOHSI. Also, through CCL, Dr. Georgopoulos has directed research efforts in the areas of physiologically based toxicokinetic and toxicodynamic modeling, in support of activities of the National Institute of Environmental Health Sciences (NIEHS) Center of Excellence at EOHSI. Currently he is a member of the Editorial Board of Stochastic Environmental Research and Risk Assessment.

Selected examples of model development and application activities for Dr. Georgopoulos include the following: He has directed the development - and multiple applications - of two comprehensive, source-to-dose modeling systems intended to support environmental health risk assessments for individuals and populations: EDMAS (Exposure and Dose Modeling and Analysis System), which was developed with base funding from ATSDR; and MENTOR (Modeling Environment for Total Risk studies), which is currently under continuing development with base funding from USEPA-ORD. Two specific implementations of MENTOR, called (MENTOR/SHEDS-1A and MENTOR/SHEDS-4M) are actually included in the listing of the CREM models (under SHEDS-MENTOR-1A and SHEDS-MENTOR-4M); they both incorporate USEPA's SHEDS (Stochastic Human Exposure and Dose Simulation) approach, expanded and recoded within the MENTOR system. The "1A" implementations (for "One Atmosphere") supports calculations of inhalation exposures to multiple co-occurring contaminants (including ozone, PM, and various air toxics); it utilizes various GIS (Geographic Information Systems) tools and incorporates "computational links" to various state-of-the-art EPA models, such as Models-3/CMAQ (Community Multiscale air Quality Model). The "4M" implementation of MENTOR/SHEDS is designed to address cumulative and aggregate exposures from "Multiple routes and Multiple pathways to Multiple contaminants in Multiple media)"; comprehensive source-to-dose applications have focused on simultaneous inhalation, oral and dermal exposures of populations to co-occurring multimedia contaminants such as arsenic and trichloroethylene.

During the last 20 years, Dr. Georgopoulos has directed numerous projects involving the application and evaluation of environmental fate and transport models, of microenvironmental and exposure models, and of biologically-based dosimetry and dose-response models. A partial list of such models includes prognostic atmospheric models such as MM5 (Mesoscale Meteorological model) and RAMS (Regional Atmospheric Modeling System); atmospheric dispersion models such as the ISC (Industrial Source Complex), ASPEN(Assessment of Pollutant Exposures Nationwide), AERMOD, CALPUFF, HPAC (Hazard Prediction Assessment Capability), and HYPACT (Hybrid Particle and Contaminant Transport) models; atmospheric chemistry/transport models such as RPM (Reactive Plume Model), UAM (Urban Airshed Model) IV and V -

including the locally developed "AERO" modifications, MAQSIP, CAMx, REMSAD and Models-3/CMAQ (Community Multiscale air Quality Model); groundwater flow and transport models such as EPACMTP, MODFLOW, and FACT (Flow and Contaminant Transport); the municipal water network model EPANET; multimedia models such as 3MRA and MEPAS (Multimedia Environmental Pollution Assessment System); and various indoor air, exposure, and dosimetry models. One of Dr. Georgopoulos currently ongoing projects involves the systematic comparison, and evaluation with field data, of comprehensive modeling systems for inhalation exposures, that include, in addition to MENTOR/SHEDS, USEPA's APEX (Air Pollution Exposure) model and HAPEM (Hazardous Air Pollutant Exposure Model); this particular three-year effort is pursued with finding from ACC (the American Chemistry Council).

Dr. Georgopoulos has participated in both research and teaching in the graduate programs of Rutgers and UMDNJ-RWJMS and has developed innovative course materials in modeling and informatics related to environmental health applications. He has been the primary doctoral thesis advisor to eighteen students, with eight Ph.D. degrees awarded since 1997, and mentor to sixteen post-doctoral fellows. His research interests involve the *development and application of novel mathematical and computational methods for diagnostic and mechanistic studies of multipathway physiochemical transport and fate processes taking place in environmental and biological systems.* Aim of this research is to improve the understanding and quantification of human exposure, biological mechanism-based dosimetry, and risk assessment, for environmental toxics; and to develop a consistent mechanistic computational framework for source-to-dose modeling of toxicant dynamics. Outcomes of this research include quantitative estimates of delivered/metabolized target tissue doses from inhalation, dietary and non-dietary ingestion, and dermal absorption of multi-pollutant mixtures.

Dr. Georgopoulos has received research funding as Principal or co-Principal Investigator, from various federal, state, and private sector agencies and organizations, including among others the USEPA, USDOE, NJDEP, NJDHSS, NIEHS, ATSDR/CDC, API, ACC, etc. He has lectured as an invited speaker at various universities, such as the Harvard School of Public Health, Johns Hopkins University, Stanford University, Illinois Institute of technology, University of Minnesota, and others. He has published research articles in several scientific journals, including *Aerosol Science and Technology, AIChE Journal, Atmospheric Environment, Bioinformatics, Chemical Engineering Science, Environmental Fluid Mechanics, Environmental Health Perspectives, Environmental Science & Technology, Environmental Toxicology and Chemistry, International Archives of Environmental Health, Journal of the Air & Waste Management Association, Journal of the American Water Resources Association, Journal of Chemical Physics, Journal of Colloid and Interface Science, Journal of Computational Chemistry, Journal of Exposure Analysis and Environmental Epidemiology, Journal of Physical Chemistry, Journal of Toxicology and Environmental health, Journal of Toxicology and Industrial Health, Marine Environmental Research, Physical Review E, Regulatory Toxicology and Pharmacology, Risk Analysis, Telus, and Water Resources Research.* He is also the author or co-author of a number of State and federal Government Documents and of numerous technical reports. He has received awards and honors including the National Award of the Society of Toxicology for best Presentation in Risk Assessment; the DuPont Education and research Award for his work on air pollution; and USEPA's Certificate of Appreciation. He served as Associate Editor of *JAWMA*, the scientific journal of the International Air and Waste Management Association , from January 1995 to June 2001, and as Guest Editor of special supplement issues of *Epidemiology* and of *Environmental Health Perspectives*. He was Co-Chair of the 1999 Joint Conference of the International Society of Exposure Analysis (ISEA) and the International Society for Environmental Epidemiology (ISEE). He currently serves as member of various national and technical committees on environmental issues.

Dr. Steven G. Heeringa:

Dr. Steven G. Heeringa is a Research Scientist and Director of the Statistical design Group at the University of Michigan Institute for Social Research (ISR) where he oversees research design for population-based studies in the social sciences, education, demography, public health and medicine. Steve has a Ph.D. in Biostatistics from the

University of Michigan and is a specialist in statistical design and analysis for studies of human and animal populations. Dr. Heeringa has over twenty-five years of statistical design experience directing the development of the ISR National Sample design as well as sample designs for ISR's major longitudinal and cross-sectional survey programs. During this period he has been actively involved in research and publication on statistical methods and procedures such as sample design methods and procedures, such as sample design, weighting, variance estimation and the imputation of missing data that are required in the analysis of sample survey data. He is an advisor to panels of the National Institutes of Health (NIH) and the World Health Organization (WHO). Since 2003, he has been a permanent member of the EPA's Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) Science Advisory Panel (SAP). He is the Director of the ISR Summer Institute in Survey Research Techniques and has been a teacher of survey sampling methods to U.S. and international students. He has served as a sample design consultant to a wide variety of international research programs based in countries such as: Russia, the Ukraine, Uzbekistan, Kazakhstan, India, Nepal, China, Iran, Chile and Egypt.

Dr. Bruce K. Hope:

Dr. Bruce K. Hope is with the Oregon Department of Environmental Quality (DEQ), where he serves as senior environmental toxicologist for the Air Quality Division and is presently responsible for establishing the Air Toxics Science Advisory Committee (ATSAC), researching reviewing and recommending air toxics benchmarks to the ATSAC for approval, and proposing recommended benchmarks for adoption as administrative rules. Previous assignments have included developing an aquatic food web biomagnification model for mercury and preparing a mercury mass balance analysis in support of the Willamette River Total Maximum Daily Loading (TMDL) process, reviewing human health and ecological risk assessments for specific cleanup sites, developing risk assessment guidance (human health, ecological, probabilistic) to support implementation of Oregon's cleanup law, and leading the State's efforts to implement probabilistic human health and population-level ecological risk assessments. Prior to joining DEQ in 1995, he was a consultant in the private sector managing human health and ecological risk assessment projects for commercial and government clients at

Comprehensive Environmental Response Compensation and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), and Base Realignment And Closure (BRAC) sites throughout the U.S. and Pacific Rim. In 2000-01, he was on leave from DEQ as an American Association for the Advancement of Science (AAAS) risk policy fellow at the U.S. Department of Agriculture in Washington, DC, where he worked on food safety, microbial risk, and bioterrorism issues.

Dr. Hope has served on several U.S. EPA advisory panels including a Scientific Advisory Panel addressing probabilistic analyses under the Federal Insecticide, Fungicide, and Rodenticide Act, the Science Review Board for the Food Quality Protection Act, a peer review workshop on the *Process for Conducting Probabilistic Risk Assessment for Superfund* and a Risk Assessment Forum workshop on probabilistic assessments. He has written peer-reviewed and technical publications on exposure modeling for human and ecological receptors, risk assessment, toxicology, and geochemistry. His modeling experience focuses on development of specialized exposure models. These have included a food web bioaccumulation model for mercury in a large river system, a series of probabilistic, spatially-explicit exposure models, and a model to enable state environmental regulators to perform population-level risk assessments.

Dr. Hope is currently the Vice-President elect of the Pacific Northwest Chapter of the Society of Environmental Toxicology and Chemistry (SETAC), chair of the Scientific Program Committee for the 2004 Fourth SETAC World Congress, and was a participant in the recent SETAC Pellston workshop on population-level ecological risk assessment. Dr. Hope is an adjunct faculty member at Oregon Health & Science University (in both the Oregon Graduate Institute and the School of Nursing), Concordia University (Portland), and the Portland State University. He holds M.S. and Ph.D. degrees in biology (aquatic toxicology) from the University of Southern California and a B.A. degree from the University of California (Santa Barbara).

Dr. Alan J. Krupnick:

Dr. Alan J. Krupnick is a Senior Fellow and Director of the Quality of the Environment Division at Resources for the Future. He is widely published in the areas of cost-benefit analysis and instrument design, with research on such topics as: the value on reduced morbidity and mortality, issues associated with revision of ozone and PM standards, optimal adders for environmental damage by public utilities, social costing of electricity, global warming and urban smog, alternative fuels, the external costs of nuclear power, measuring the effects of urban transportation policies on the environment, weighing environmental uncertainties, the benefits and cost of Superfund cleanups and many other related topics. He has served as Senior Economist in the Council of Economic Advisors (1993-94), consultant to the US Agency for International Development (US AID), World Bank, Health Canada, the European Commission, the Harvard Institute for International Development, the US Congressional Office of Technology Assessment, the University of Missouri, the State of Maryland, the National Commission on Water Quality and other organizations. He has extensive experience in using models for estimating the benefits and costs of environmental policies. He is one of the founders of the Tracking and Analysis Framework (TAF), a series of models based in Analytica which is available on the web. This model uses a damage function approach to estimate the health and other benefits from air emissions reductions. He also has used Analytica to build a model of the benefits of fish advisories for mercury. The paper is available on RFF's website and from the National Oceanic and Atmospheric Administration (NOAA). He has also made much use of the emissions and cost database from Pechan and Associates, tied to TAF, for estimating the benefits and costs of alternative air pollution trading policies. This work has been published in numerous places. He also has been a Principal Investigator (PI) for path breaking work on the development of source-receptor matrices from use of the Georgia Tech air quality model, one of the feeder models to MODELS-3. In addition, he has been a peer reviewer for models of this type, for the European Union (EU), the United Kingdom (UK's) EPA, and most recently, for EPA's BENMAP.

Dr. Krupnick has provided expert testimony to the U.S. Congress on implementation and enforcement of the Clean Air Act, the Regulatory Reform Bill in

Congress, reforming Superfund risk assessment, cost-effectiveness and cost-benefit analysis and related topics. Dr. Krupnick has been a reviewer for over a dozen journals in the topics of valuation, cost-benefit analysis and related topics. He is currently serving on several Panels organized by the National Academy of Sciences' Transportation Research Board, and has served on many other expert committees, including one from the Royal Society of Canada on the socioeconomic analysis of possible Canada-wide ozone and fine particulate standards. He was also a co-chair of a major EPA-led stakeholder process on implementation of new ozone and fine particulate ambient air quality standards.

Dr. Krupnick has his Ph.D and M.A. in Economics from the University of Maryland, and his B.S. in Finance from Pennsylvania State University.

Dr. Randy L. Maddalena:

Dr. Randy L. Maddalena, Ph.D., is a Scientist in the Chemical Exposure and Risk Analysis Group within the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory. He received his BS in Environmental Toxicology (1992) and his Ph.D. in Agricultural and Environmental Chemistry (1998) from the University of California, Davis. The primary focus of his research is development, evaluation and application of models that predict chemical fate in multiple environmental media (air, water, soil, vegetation, sediment) and chemical exposures through multiple pathways (drinking water, food, feed, indoor air) for both human and ecological receptors. He also develops tools and methods for performing probabilistic risk assessment and sensitivity analysis applied to complex regulatory models. His most recent work combines the use of models and experimental data to investigate how vegetation influences the environmental fate and transport of semi-volatile organic pollutants and how the uptake of these pollutants into ecological or agricultural food chains might contribute to dietary exposures.

Dr. Maddalena is a Co-Chair of the Society of Environmental Toxicology and Chemistry (SETAC) Advisory Group on Fate and Exposure Modeling where he serves as an Editor of the SETAC Globe's Fate and Exposure Modeling column. He is a member of the SAB's Integrated Human Exposure Committee (IHEC) and has participated in several recent SAB reviews including Ranking Air Toxics Indoors, The Human Health Research Strategy and the Multi-Media, Multi-Pathway, and Multi-Receptor Risk Assessment (3MRA) Model Review Panel. In the last five years, Dr. Maddalena had received funding from the EPA's National Exposure Research Lab. for fate and exposure model development; the DOE's Fossil Energy Program for experimental work on plant uptake of petroleum related hydrocarbons; the DOE's Office of River Protection for a Merit Panel review of the C-Tank Farm Closure Performance Assessment at the Hanford Nuclear Reservation; the EPA's Office of Air Quality Planning and Standards for work on the Total Risk Integrated Methodology (TRIM.FaTE) model; and the EPA's Office of Emergency and Remedial Response for method development related to probabilistic risk assessment.

<u>Dr. June Fabryka-Martin:</u>

Dr. June Fabryka-Martin is a Staff Scientist in the Environmental and Earth Sciences Division at Los Alamos National Laboratory (LANL) in Los Alamos, NM. She holds a PhD and MS in Hydrology and Water Resources from the University of Arizona and received a BA degree in Geography from the University of Delaware. Her dissertation dealt with terrestrial production of radioactive isotopes by natural nuclear reactions initiated by cosmic rays and a wide variety of energetic subatomic particles. Dr. Fabryka-Martin's work experiences span a broad range of topics related to radiological issues, including the use of Monte Carlo N-Particle (MCNO) transport code to model radiation fluxes and nuclear reaction rates in geologic media as part of international studies pertaining to the geochemistry of long-lived fission products and plutonium in uranium ore deposits; interpreting geochemical and isotopic compositions as indicators of groundwater flow paths and residence times; characterizing transuranic waste streams produced by LANL activities, including data quality assessments; and developing and evaluating the effectiveness of methods to mitigate the production and dispersion of particulates during open-air experiments. Her Yucca Mountain studies of spatial distributions of chloride and chlorine-36 in the subsurface played significant roles in the development and testing of hydrologic process models for assessing the viability of this site as a geologic repository for radioactive waste, in particular by highlighting the potential role of fast transport paths in this geologic setting. Her data were used to develop and test alternative conceptual models of site infiltration, to calibrate and bound numerical site infiltration models, to constrain property values used in the unsaturated-zone site-scale flow and transport model FEHM (Finite Element Heat and Mass Transfer Code), and to calibrate the Unsaturated-Zone Radiological Transport Model (UZ RTM) using the software codes FRACL, TOUGH2, and T2R3D.

Dr Fabryka-Martin contributed to two recent books dealing with transport in the unsaturated zone, including development of the conceptual model of unsaturated zone hydrology at Yucca Mountain, and iodine-129 in a text on environmental tracers in subsurface hydrology. She has published over 35 refereed journal articles and conference papers in published proceedings and has frequently reviewed manuscripts that use modeling codes to predict production and transport rates of particles and chemical species. Dr. Fabryka-Martin has served as a member of the US EPA Science Advisory Board's Radiation Advisory Committee, and was senior editor for the SAB's recent review of the Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Manual. She has contributed to over 10 SAB reports and advisories over the past decade, including those reviewing the Agency’s use of such models as the Multi-Media Contaminant, Fate, Transport and Exposure Model (MMSOILS), PATHRAE (a US EPA low-level radioactive waste environmental transport and risk assessment code, methodology & user’s manual), Prediction of Radiological Effects due to Shallow Trench Operations (PRESTO), and Residual Radioactive Materials Guidelines (RESRAD).

As a LANL employee, Dr. Fabryka-Martin works for the University of California on projects funded by the US Department of Energy and the National Nuclear Security Agency.

Mr. David Merrill:

Mr. David Merrill, a Principal at Gradient Corporation, has 15 years of experience in negotiating technically sound and cost effective solutions to environmental contamination problems. His expertise includes directing large-scale, multi-disciplinary risk assessments, multimedia chemical fate and transport modeling, complex data analysis, and database design for systems such as landfills, lagoons, chemical plants, Manufactured Gas Plants (MGPs), river systems, and groundwater contaminant plumes. With his extensive risk assessment experience and strong engineering background, he has negotiated risk-based cleanup levels and remedial strategies, interpreted complex site investigation data into effective conceptual site models, and evaluated many types of contaminant transport conditions, including multimedia transport in water, sediments, and air. He has worked extensively with Polychlorinated Bi-Phenyls (PCBs), solvents, metals and Non-Aqueous Phase Liquids (NAPLs) and has served as an expert on cases involving Potentially Responsible Party (PRP) cost allocation disputes. Mr. Merrill has prepared technical comments on behalf of industry and trade organizations on Agency regulations including the PCB Megarule and multimedia modeling and risk assessment aspects of the Land Disposal Rule (LDR) and the Hazardous Waste Identification Rules (HWIR).

All of Mr. Merrill's professional work is performed for Gradient. Gradient's client base includes Fortune 500 companies, law firms, trade associations, and to a lesser extent state and local municipalities and regulatory agencies. Over the last two years Mr. Merrill's clients have included law firms representing individual companies and PRP groups, trade associations, chemical companies, natural gas pipeline and oil companies, energy generation companies, and the U.S. EPA. Mr. Merrill received his B.S. in Soil and Water Science from the University of California at Davis, and his M.S. in Agricultural Engineering (Civil/Environmental Engineering focus) from Cornell University where he also completed the course work and qualifying exams toward a doctorate degree.

Dr. Paulette Middleton:

Dr. Middleton has 30 years experience leading air quality programs that inform air quality policy using air quality and related assessment tools. For example, she developed and applied a number of urban aerosol dynamics models, was a leader on the modeling team that created the Regional Acid Deposition Model (RADM), extended RADM to include aerosol dynamics -- DAQM (Denver Air Quality Model) and applied DAQM to studies of visibility in the Front Range of Colorado, led the development and application of the integrated assessment of scenarios (i.e., linking air quality to economic, environmental and social impacts and driving forces using a variety of modeling approaches) for visibility protection in the Western US as the cornerstone of the Grand Canyon Visibility Transport Commission efforts, created and applied a Visibility Assessment Screening Technique to illustrate differences in visibility changes resulting from SO2 and NOX emission reductions in different areas of the US, modified and applied ICST and related models to explore the impacts of chemical by-products in the vicinity of point sources, led the design of integrated analysis systems applied to air quality and climate related problems, lead author of air quality modeling and application reviews, and has been serving as an expert advisor to a number of programs using integrated modeling systems as well as individual air quality models.

Dr. Middleton's previous EPA Science Advisory Board service includes: Chair of the Air Quality Modeling Subcommittee (AQMS) evaluating EPA's assessment of the benefits and costs of the Clean Air Act; Member of the Environmental Modeling Committee responsible for the recent review of the National Air Toxics Assessment, which included an evaluation of mercury and toxic VOC risk assessment; Member of the Research Strategy Advisory Committee, which provided direction to EPA on critical research needs; Member of the Clean Air Science Advisory Committee during its review of the current ozone and fine particulate matter standards; and Member of the Environmental Futures Subcommittee developing guidelines for EPA foresight.

Dr. Middleton has been director of the NSF and NASA funded Global Emissions Inventory Activity (GEIA) Center, located at http://geiacenter.org/, since GEIA's inception in 1990. Currently, she is a Special Advisor, providing advice on adequacy of air quality modeling and developing issue papers to help inform policy for several organizations, including Environmental Defense, Western Resource Associates, Yellowstone Coalition, Northern Cheyenne Indian tribe, EPA Region 8, Colorado Department of Public Health & the Environment; U.S. Department of Justice; and State of New Jersey, Division of Law. Previously she held research, program development and leadership/executive positions at the National Center for Atmospheric Research, Atmospheric Sciences Research Center at the State University of New York at Albany, Science & Policy Associates, and RAND. In 2002, she created Panorama Pathways, http://panoramapathways.net. She has developed and applied a variety of air quality models, has over 100 publications, most of which are peer-reviewed, and has led a number of programs using air quality modeling to improve policymaking.

Dr. Mitchell J. Small:

Dr. Mitchell Small is the H. John Heinz III Professor of Environmental Engineering at Carnegie Mellon University, with appointments in the departments of Civil and Environmental Engineering, and Engineering & Public Policy. He joined Carnegie Mellon in 1982 following completion of his Ph.D. in Environmental & Water Resources Engineering from the University of Michigan. At Carnegie Mellon, Professor Small serves as the Associate Department Head for Graduate Education in the Department of Engineering & Public Policy. He has also worked as a consulting engineer, with Hydroscience, Inc., from 1975-1978. Dr. Small's research involves mathematical modeling and statistical evaluation of environmental quality, exposure and risk. He has developed methods for statistical modeling of variability and uncertainty for air, soil, surface-water and ground-water problems. His recent work has evolved to consider the impact of human risk perception and behavior in integrated exposure assessment, and has included collaboration with statisticians, toxicologists, economists, and behavioral and decision scientists. Current applications include the study of regulations and risk communication for drinking water utilities, decision support for site and soil remediation, and integrated assessment of hazardous air pollutants. Support for this research has come from a number of government agencies and private industry, including a National Science Foundation Presidential Young Investigator Award from 1986-1991.

Professor Small has been active in providing advice to the US Environmental Protection Agency, first as a member of the Science Advisory Board (SAB), Environmental Engineering Committee, 1985-1991, and currently as Chair of the Environmental Models Subcommittee. He also served as a member of the U.S. EPA Office of Research and Development Board of Scientific Counselors (BOSC, 1996-2002). He has served on a number of National Research Council Committees reviewing issues of environmental contamination and risk in the United States, most recently the Board on Environmental Studies and Toxicology (BEST) study on changes in New Source Review Programs for Stationary Sources of Air Pollutants. He currently serves as an Associate Editor for the *Journal Environmental Science & Technology*, with particular responsibility for the Policy Analysis section, and was elected as a Fellow of the Society for Risk Analysis in 2003.

Dr. Douglas G. Smith:

Dr. Douglas G. Smith, Sc.D. currently serves as Principal Environmental Health Scientist in the Risk Assessment Department of ENSR International, an environmental consulting company with a total of 70 worldwide offices. Dr. Smith's academic background includes a BA in Physics from Franklin and Marshall College and an MS and Sc.D. in Environmental Health Sciences from Harvard University School of Public Health. His specialties in environmental health sciences include air pollution transport and risk analysis, radiological health, as well as chemical process safety and related emergency preparedness assessment and planning.

Dr. Smith has more than 25 years experience as an environmental risk assessment and risk management consultant. Early in his career he worked as a researcher in the Harvard Air Cleaning Laboratory working on detection methods for trace levels of rare gases in the atmosphere. His subsequent service in the U.S. Public Health Service Bureau of Radiological Health involved research on the dispersion of radioactive gases from reprocessing nuclear fuels, and the comparison of field test data with the early versions of the Pasquill/Giford/Turner atmospheric dispersion models that were being applied for chemical pollutants by the newly formed US EPA. After completing a thesis related to micro scale atmospheric dispersion near buildings, in 1974 he joined Environmental Research and Technology (ERT, now ENSR) to work on the development and verification testing of new versions of air transport models, such as the Egan-Mahoney 2-dimensional grid advection diffusion model (EGAMA) for automotive and aircraft sources, including a custom model for dispersion of the Concorde's emissions at Dulles Airport. For later mobile source permitting projects EGAMA use was replaced by CALINE (California Line Source model). For power plants, his experience with application and sensitivity testing of ERT's MPSDM-6 (Multiple Point Source Dispersion Model 6), and the addition of its building-wake submodel, led to his own team's development of NPSDM (Nuclear Plant Source Dispersion Model) for site safety analysis, plus a customized EGAMA-like model: SEABREEZE (Sea Breeze Model), which was accepted by the Nuclear Regulatory Commission for use at the Pilgrim Nuclear Plant site - - based on successful comparison with site and near-site data.

In the 1980's, Dr. Smith led a privately funded field verification study of the Industrial Source Code (ISC) model with a team that performed dual-tracer releases from 500-ft and1000-ft stacks (with aerial and ground-level sampling) for an Ohio Edison power plant on the Ohio River. In the mid-80's and 90's he turned to model development and applications needed for assessing risks near chemical plants and incinerators. He led a team in developing HASTE (Hazard Assessment System for Toxic Emissions), a real-time accidental chemical and spill modeling system that incorporated AIRTOX (Air Toxicity exposure model), an ENSR model accepted by EPA and several individual states as an accepted alternative to the RMP*COMP (Risk Management Plan Computation) model available from EPA. Although original development funding was provided by ENSR, HASTE was sold as a package system to several large chemical, manufacturing, and oil companies to be used primarily for training and preparedness planning.

Dr. Smith has authored more than 25 publications and technical presentations on air and multipathway model application to hazardous air pollutant issues, accidental release assessment and risk communication. Although his consulting work has historically included applied R&D projects for state and federal agencies, but over the last fifteen years has primarily been providing clients in chemical, pharmaceutical, paper, food, and energy production industries with practical advice of the functional, regulatory, and training requirements for their short-term and long-term risk management programs, particularly the incineration of hazardous waste materials to minimize environmental impacts. Current research activities have been limited to those supported by ENSR's internal R&D, with occasional cooperative programs funded by industry trade organizations (such as the Electric Power Research Institute, the Louisiana Chemical Association, the American Chemistry Council), but none are currently active.

Dr. Smith's experience on practical model application includes critical analyses (circa 1995-6) of the role/form of submodels for dioxin deposition used with ISCST3 (Industrial Source Code Short-Term 3) and its interim (draft) predecessor ISCSTDFT (industrial Source Code Draft), and in the application with these models to a set of associated fate and exposure and risk models at more than a dozen sites. Dr. Smith served on a peer review panel in 2000 for the U.S. EPA's review of their "Combustor Risk Assessment" guidance. In 2003 he was appointed to serve on the SAB panel reviewing the Multi-Media, Multi-Pathway, and Multi-receptor Risk Assessment (3MRA) Modeling System. The 3MRA System includes ISCST3 and a similar set of models and statistical tools designed to help EPA assess on a national basis the benefits from alternative risk management practices for classification, storage and disposal of RCRA-regulated materials. His work on that SAB panel has now essentially concluded, as the final report is proceeding through the SAB and EPA administrative review process.

Dr. James H. Smith:

Dr. James H. Smith is the lead photochemical modeler in Texas Commission on Environmental Quality, and the state expert on all modeling activities, including management for State Implementation Plan (SIP) activities for the Houston/Galveston/Brazoria ozone non-attainment area in Southeastern Texas. He is responsible for coordinating all phases of modeling for demonstrating compliance with federal clean air standards in the area, including development of modeling protocols, conceptual models, modeling inventories, model performance evaluation, evaluation and interpretation of model results, and documentation. Dr. Smith is recognized and consulted at a global level in the area of photochemical modeling and air quality research in general, including atmospheric transport, transformation and removal, sensitivity analysis, exposure assessment, decision analysis, computer sciences, spatial modeling, statistics, and quality assurance procedures. As one of the top modeling experts in the country, he frequently presents his findings to national audiences at the highest levels of technical expertise, as well as to the general public and government officials. In support of SIP development activities, Dr. Smith is also involved with modeling analyses conducted for the Beaumont/Port Arthur and Dallas/Fort Worth ozone non-attainment areas. Recently, he coordinated the incorporation of the 2000 Texas Air Quality Study analysis into modeling for the Texas Gulf coast area.

Dr. Smith has very broad-based experience in regulatory modeling. With a Ph.D. in Mathematics, and focus on statistics, he began his career with the Texas air program in 1992 performing a variety of programming and analytical tasks. Besides running the Urban Airshed Model, Dr. Smith developed emissions input data for Area, Nonroad Mobile, Onroad Mobile, Point, and Biogenic sources for the state of Texas and the entire modeling domain, which extends to the eastern half of the country. He was instrumental in launching the Texas air program on a path of developing the most advanced modeling inventory in use in any regulatory application in the world. Dr. Smith also developed sophisticated graphical tools to quality assure model input and output, and to present results in a clear and concise manner. In his twelve years with the Texas air program, Dr. Smith has acquired considerable experience in personnel management, contract administration, budgeting, and project management.

Prior to working for the State of Texas, Dr. Smith worked for three years at the Johnson Space Center developing automated remote sensing systems for agricultural applications, then for seven years at a software company developing, coding, and supporting a commercially marketed modeling system for mainframe computer system capacity management.

Dr. Smith has authored or co-authored over twenty journal articles or significant conference presentations and hundreds of presentations for smaller groups such as local Air & Waste Management Association meetings, user group meetings, EPA workshops, and stakeholder groups. He has authored and/or edited substantial portions of twelve major revisions of the Texas State Implementation Plan.

As a member of the Texas Commission on Environmental Quality's Science Coordinating Committee for Air Research, Dr. Smith has been one of the primary advocates for application of federal and state grants for the advancement of air research, that on an annual basis typically exceeds $5M. He also participates in the assessment phase of projects selection for various research institutions in the Texas, and has been the technical manager for various subcontracted air research projects by the Technical Commission on Environmental Quality.

Dr. Smith has twice been honored as an Employee of the Year, and twice as a Team of the Year member by the Texas Commission on Environmental Quality. He is a member of the Air & Waste Management Association.

<u>Dr. Thomas L. Theis:</u>

Professor Thomas L. Theis is Director of the Institute for Environmental Science and Policy at the University of Illinois - Chicago (UIC), a center that focuses on the development of new cross-disciplinary research initiatives in the environmental area. He was most recently at Clarkson University, where he was the Bayard D. Clarkson Professor and Director of the Center for Environmental Management. Professor Theis received his doctoral degree in environmental engineering, with a specialization in environmental chemistry, from the University of Notre Dame.

Professor Theis' areas of expertise include the mathematical modeling and systems analysis of environmental processes, the environmental chemistry of trace organic and inorganic substances, interfacial reactions, subsurface contaminant transport, hazardous waste management, industrial pollution prevention, and industrial ecology. He has been principal or co-principal investigator on over fifty funded research projects totaling in excess of eight million dollars, and has authored or co-authored over one hundred papers in peer reviewed research journals, books, and reports. He is a member of the US EPA Science Advisory Board, and has been involved in a number of modeling-related reviews, including Model Use Acceptablility Criteria, Total Risk Integrated Methodology (TRIM), and his most recent activity as Chair of the Multi-Media, Multi-Pathway and Multi-Receptor Risk Assessment (3MRA) Panel of the SAB, as well as other modeling related activities.

He is past editor of the *Journal of Environmental Engineering* and has served on the editorial boards of *The Journal of Contaminant Transport*, and *Issues in Environmental Science and Technology*. From 1980-1085 he was the co-director of the Industrial Waste Elimination Research Center (a collaboration of Illinois Institute of Technology and University of Notre Dame), one of the first Centers of Excellence established by the USEPA. In 1989 he was an invited participant on the United Nations' Scientific Committee on Problems in the Environment (SCOPE) Workshop on Groundwater Contamination, and in 1998 he was invited to by the World Bank to assist in the development of the first environmental engineering program in Argentina. He is Principal Investigator of the Environmental Manufacturing Management Program, one of the Integrative Graduate Education Research and Training (IGERT) grants of the National Science Foundation, which involves research on industrial pollution prevention problems emphasizing a systems approach. In 2002, he became the first permanent director of the UIC Institute for Environmental Science and Policy.

Dr. Richard L. Wetzel:

Dr. Richard L. Wetzel is Professor of Marine Science and Chair of the Department of Biological Sciences at the Virginia Institute of marine Science and School of Marine Science at the College of William and Mary where he has been a member of the faculty since 1975. Dr. Wetzel received his B.S. (1969) and M.S. (1971) degrees in

Biology and Marine Science from the University of West Florida and Ph.D. (1975) in Zoology and Ecology from the University of Georgia. His research interests have focused over the past 30 years on carbon - nitrogen cycling in estuaries, top - down and bottom - up controls on ecosystem processes, and specifically ecosystem process modeling and simulation analysis. He is the author or co-author of more than 70 papers and technical reports in these areas. He has given particular attention to modeling physical and chemical controls on aquatic primary production (seagrasses, marsh macrophytes and phytoplankton) and the interactive effects of light, nutrients and grazing on these important estuarine communities. He has also developed ecosystem simulation models as an integrative tool for the synthesis of data over various temporal and spatial scales, as a guide to building research programs by identifying information or data gaps, and by exploring controls on ecosystem dynamics through simulation analyses that address contemporary environmental issues. He has expanded the modeling program to the watershed level through the development of BasinSim 1.0, a Windows - based watershed modeling package that simulates the loading of carbon, nitrogen, phosphorus and sediments to aquatic systems in small to medium sized basins. Most recently, he has been involved in multispecies modeling efforts for the development of ecosystem based management plans for fisheries. These efforts have been supported over the years by grants from both state and federal agencies including the NSF, EPA, and NOAA. In addition, Dr. Wetzel has served on numerous working groups and review panels dealing with estuarine ecology in general and ecological modeling in particular and has organized and chaired several special sessions at international professional meetings on the development and application of models in ecology.

Dr. Peter Wilcoxon:

Peter J. Wilcoxen is an Associate Professor in the Departments of Economics and Public Administration at Syracuse University's Maxwell School, and he is also a Nonresident Senior Fellow at the Brookings Institution. He received his BA in physics from the University of Colorado and his AM and PhD in economics from Harvard University.

Dr. Wilcoxen's principal area of research is the effect of environmental and energy policies on economic growth, international trade, and the performance of individual industries. His work often involves the design, construction and use of large-scale intertemporal general equilibrium models. He is coauthor of the Jorgenson-Wilcoxen Model, a thirty-five-sector econometric general equilibrium model of the US economy that has been used to study a wide range of environmental, energy and tax policies. He is also coauthor of G-Cubed, an eight-region, twelve-sector general equilibrium model of the world economy which has been used to study international trade and environmental policies. In addition, he is a coauthor of a graduate-level textbook on general equilibrium modeling. Many of his recent publications have focused on national and international policies to control climate change.

Dr. Wilcoxen's past positions include: Associate Professor of Economics, the University of Texas at Austin; Assistant Professor of Economics, the University of Texas at Austin; Visiting Fellow, the Brookings Institution; Visiting Scholar, Harvard University, and Senior Research Fellow, the University of Melbourne in Australia. His research has been funded by the Environmental Protection Agency, the Department of Energy, the US Geological Survey and the National Science Foundation.

APPENDIX F - ACRONYMS

[NOTE: Acronyms include most cited text and Appendix terminology, except for terminology that may be found in Appendix E Panel Biosketches. Acronyms will be completed and re-checked, once the final text edits are in place. - - - KJK]

AA-ship	Assistant Administrator-ship (within the U.S. EPA)
ADV	Advisory
ANSI	American National Standards Institute
AQCS	Analytical Quality Control Services
AQUATOX	It is a tool in performing ecological risk assessments for aquatic ecosystems. It is a personal computer (PC)-based multi-stressor and multi-response ecosystem model that simulates the transfer of biomass and chemicals from one compartment of the ecosystem to another. It does this by simultaneously computing important chemical and biological processes over time. It predicts the fate of various pollutants, such as nutrients, organic toxicants and various chemicals in aquatic ecosystems, as well as the direct and indirect effects on the resident organisms and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. It has the potential to help establish the cause and effect relationships between chemical water quality and the physical environment and aquatic life.
ArcINFO	A Geographic Information Modeling System

ASQC — American Society for Quality Control

ASTM — American Society for Testing and Materials

BLP — Buoyant Line and Point source Gaussian plume dispersion model designed to handle unique modeling problems associated with air dispersion phenomena

BMPs — Best Management Practices

CAA — Clean Air Act

CALPUFF — A multi-layer, multi-species non-steady state puff air dispersion model that simulates the effects of time- and space-varying meteorological and air quality conditions on pollution transport, transformation, and removal for assessing long range transport of pollutants and their impacts.

CEAM — Center for Exposure Assessment Modeling (U.S. EPA/ORD)

CERCLA — Comprehensive Environmental Response Compensation and Liability Act

CFR — Code of Federal Regulations

CLEAN — Crops, Livestock and Emissions from Agriculture in the Netherlands: A Modeling Tool to Evaluate Policy Options for Reduction of Mineral Surplus, Ammonia Emissions to Air and Nitrogen and Phosphate Emissions to Soil

CLEANER	Collaborative Large-Scale Engineering Analysis Network for Environmental Research. A networked infrastructure of environmental field facilities that enables formulation and development of engineering and policy options for the restoration and protection of environmental resources.
CMAQ	Community Multi-Scale Air Quality Model designed to simulate and model a wide range of physical and chemical processes relating to air quality at particular scales in the lower atmosphere.
CONCEPT	World Health Organization Concept Model of Children's Environmental Health Indicators which emphasizes the complex relationships between environmental exposures and children's health
CQ	Charge Question
CREM	Council for Regulatory Environmental Modeling
CWA	Clean Water Act
D	Dimension (e.g., as 1-D, 2-D, etc.)
DECISIONDOCS	A Central Database and Clearing House Information System for Communication, Outreach, Terminology, Environmental Data for Monitoring, TMDLs, Water Quality, Ground Water Monitoring, etc.
DFO	Designated Federal Officer

DOWNLOADINFO	A Listing of US EPA Environmental Models to Provide Information on Dispersion Models Supporting Regulatory Programs Required by U.S.Law
DQO	Data Quality Objectives
EEC	Environmental Engineering Committee (U.S. EPA/SAB/EEC)
EPA	Environmental Protection Agency (U.S. EPA)
EPANET	Environmental Protection Agency Network simulation model. A windows program that performs extended period water network modeling simulation of hydraulic and water-quality behavior within pressurized pipe networks. It tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network using a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.
FACA	Federal Advisory Committee Act (Public Law 92-463)
FACT	Flow and Contaminant Transfer Model
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FR	Federal Register
GAQM	General Air Quality Model (Also Guideline on Air Quality Models)

GCVTC	Grand Canyon Visibility Transport Commission
HTTP	Hypertext Transfer Protocol (world wide web protocol)
IQG	Information Quality Guidelines
IPM	Integrated Planning Model. This model is used by the U.S. EPA to analyze the projected input of environmental policies on the electric power sector in the 48 contiguous states and the District of Columbia. It is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector. It provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting energy demand and environmental transmission, dispatch and reliability constraints.
KBase (also MKB)	Models Knowledge Base
LP	An atmosphere-ocean model code for accumulation and printing of diagnostics for ocean dynamics (NOTE: There may be other meanings. See, for instance Appendix C-4, 3rd paragraph - - - KJK)
MKB (also KBase)	Models Knowledge Base
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NCSU	North Carolina State University

NEPA	National Environmental Protection Act
NERL	National Exposure Research Laboratory (U.S. EPA/ORD/NERL)
NIST	National Institute of Standards and Technology
NMSE	Normalized Mean Square Error
NRC	National Research Council [of the National Science Foundation (NSF)]
NSF	National Science Foundation
NTIS	National Technical Information Service
NWPCAM	National Water Pollution Control Assessment Model. It combines water quality modeling with economic analyses to translate concentration estimates to measures of “beneficial use attainment” used to characterize water quality for policy purposes. This is a national-level water quality modeling system that can simulate water quality changes and economic benefits that result from pollution control policies. It can develop place-specific water quality estimates for most of the nation’s inland region.
OAT	Office of Air Toxics (of the U.S. EPA)
OECA	Office of Enforcement and Compliance Assurance (U.SA. EPA/OECA)
OECM	Office of Enforcement and Compliance Monitoring

OMB	Office of Management and Budget (U.S. OMB)
ORD	Office of Research and Development (U.S. EPA/ORD)
PCBs	Polychlorinated Bi-Phenyls
PDF	Portable Document Format (Also Probability Distribution Function – depends on context)
PEST	Non-linear parameter estimation software for any numerical model
POPs	Persistent Organic Pollutants
PRIZM	A risk assessment model for pesticides to estimate environmental concentrations in surface waters (e.g., PRIZM/EXAMS). (Acronym ? - - - KJK)
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plans
QC	Quality Control
QUA	Quantitative Uncertainty Assessment

QUAL2E	An enhanced stream water quality model which is applicable to well-mixed dendritic streams. It simulates the major reactions of nutrient cycles, algal productions, benthic and carbonaceous demand, atmospheric reaeration and their effects on predicting temperature fluctuations on the dissolved oxygen balance. It is intended as a water quality planning tool for developing total maximum daily loads (TMDLs) and can also be used in conjunction with field sampling for identifying the magnitude and aquatic characteristics of non-point sources.
QUAL2EU	This is an enhancement to QUAL2E which allows users to perform three types of uncertainty analyses, namely sensitivity analysis, first order error analysis, and Monte Carlo simulation.
RAIMI	Regional Air Impact Modeling Initiative. A regional air impact modeling tool which is a set of software tools developed by U.S. EPA Region 6 to integrate emissions inventories, air dispersion models, risk models, and population models. EPA and state and local agencies can use this risk-based tool to evaluate the cumulative health impact on local communities of virtually an unlimited number of emissions sources. It has the ability to both predict potential risk to individual neighborhoods and differentiate from hundreds of pollution sources to a few where attention will yield the greatest health benefit. Results are generated in a fully transparent fashion such that risk levels are traceable to each source, each exposure pathway (e.g., inhalation, ingestion),and each contaminant, allowing for prioritization of remedial action based on the potential impact of a contaminant or source on human health.

RCRA	Resource Conservation and Recovery Act
REM	Regulatory Environmental Modeling
REM Panel	Regulatory Environmental Modeling Panel (U.S. EPA/SAB/REM Guidance Review Panel; also referred to as "the Panel")
REV	Review
SAB	Science Advisory Board (U.S. EPA/SAB)
SCRAM	Support Center for Regulatory Air Models
SDWA	Safe Drinking Water Act
SI	International System of Units (from NIST)
SWIMODEL	A (Also referred to as SWMM) dynamic rainfall-runoff storm water management simulation model, primarily but not exclusively for urban areas, for single event or long-term (continuous) simulation. Flow routing is performed for surface and sub-surface conveyance and groundwater systems, including the option of fully-dynamic hydraulic routing. Non-point source runoff quality and routing may also be simulated, as well as storage, treatment and other best management practices (BMPs).
THERdbASE	Total Human Exposure Risk Database and Advanced Simulation Environment model. An integrated database and analytical modeling software system for use in exposure assessment calculations and studies.

TMDL	Total Maximum Daily Loading
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. This tool assists in impact assessment for sustainability metrics, life cycle assessment, industrial ecology, process design and pollution prevention.
TRIM_FATE	Total Risk Integrated Methodology Model FATE Module [It is an overall modeling framework intended to provide a flexible method for integrating the release(s) of pollutants from single or multiple sources to their multimedia, multipathway movement in order to predict exposure to pollutants and to estimate human health and ecological risks.]
TSCA	Toxic Substances Control Act
UK	United Kingdom
URLs	Uniform Resource Locators
VOI	Value of Information

WASP	Water Quality Analysis Simulation Program. This is a generalized framework for modeling contaminant fate and transport in surface waters and is used in TMDL water quality modeling applications. It is based on the flexible compartment modeling approach, and can be applied in one, two, or three dimensions. It is designed to permit easy substitution of user-written routines into program structure. Problems typically studied include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination and organic chemical and heavy metal contamination.
WoE	Weight-of-Evidence

End of Document