May 18, 2010

Dr. Paul Anastas
Assistant Administrator
Office of Research and Development
U.S. Environmental Protection Agency

Dear Dr. Anastas:

This is a report from the Board of Scientific Counselors (BOSC) conveying the proceedings of the Decision Analysis Workshop, jointly held by ORD and the BOSC on March 30–April 1, 2009. The workshop was intended to assist ORD in examining decision analysis options to improve its strategic planning, maximize research efficiency, and improve prioritization and decision-making processes, while doing so in a more structured, objective, and transparent manner.

The workshop consisted of presentations from experts in the field of decision analysis and panel discussions focusing on specific approaches that could be used in three ORD case studies. The panels also discussed the difficulties that organizations such as ORD face in using structured approaches to decision making, but also offered suggestions for their successful implementation.

Several key observations resulted from the workshop, and they are summarized in this report. These observations were used by the BOSC to develop specific recommendations for ORD. The BOSC would like to continue the discussion with ORD on the use of decision analysis techniques, and would therefore request that ORD respond to the recommendations in this report.

We expect that this BOSC report will assist ORD in continuing to improve its decision-making processes. On behalf of the BOSC Executive Committee, it is my pleasure to transmit this report to you.

Sincerely,

Gary S. Sayler
Chair, Board of Scientific Counselors

PROCEEDINGS OF THE
U.S. ENVIRONMENTAL PROTECTION AGENCY

BOARD OF SCIENTIFIC COUNSELORS DECISION ANALYSIS: SUPPORTING ENVIRONMENTAL DECISION MAKERS WORKSHOP

CINCINNATI, OH
MARCH 30 – APRIL 1, 2009

Executive Summary

The ultimate objective of the United States Environmental Protection Agency (EPA) is to protect human health and the environment, and EPA's Office of Research and Development (ORD) is tasked with developing a research portfolio to support the various Agency activities designed to achieve that objective. ORD must evaluate strategic research options in a complex and uncertain decision-making environment and in the face of increased pressure to maximize research efficiency. A primary objective in strategic planning is identifying new areas of opportunity and establishing research priorities to best meet current and future objectives under existing and expected constraints. The complexity and uncertainty surrounding such a prioritization creates a challenge for decision makers and often results in a "laundry list" of all possible needs and problems, without clear definition as to which options are the most important and what the process for prioritization entailed. This tendency may make effective communication of research priorities difficult if not impossible and creates the perception that priorities are established in an opaque and subjective manner. While objective criteria may be, and typically are, used to prioritize research options, a formalized record of the decision analysis process or an established or standardized framework for prioritization often is absent.

At the September 11-12, 2008 Board of Scientific Counselors (BOSC) Executive Committee Meeting, Dr. Fred Hauchman of EPA's Office of Science Policy (OSP) suggested that using value of information (VOI) techniques to prioritize research by more formally identifying the research that would most reduce uncertainty would be a beneficial strategy for ORD to take in evaluating research priorities. VOI is a specific decision analytic technique that quantifies the value (in monetary or other terms) associated with reducing uncertainty prior to making a decision. Dr. Hauchman indicated that ORD would be receptive to recommendations from the BOSC on the best way to proceed with respect to institutionalizing the use of VOI and other related techniques to support research prioritization and decision making within ORD. Although VOI is appropriate for specific kinds of decisions, it is not always the optimum analytical method nor is it the only available method. To better understand how decision analysis techniques would be applicable and used more broadly for particular kinds of decisions, the BOSC resolved to hold a workshop to hear from experts in the field and from those at other agencies who have grappled with these issues.

Consequently, the BOSC and ORD's National Risk Management Research Laboratory (NRMRL) organized a 2-day workshop, which was held on March 30–April 1, 2009, at EPA's facility in Cincinnati, Ohio. The first day of the workshop consisted of presentations from experts in the field (see the attached workshop agenda). The second day consisted of a panel discussion based on the three case studies to explore the kinds of decisions that would be most appropriately addressed by specific approaches. The panel also discussed the difficulties in transitioning an institution to a more structured approach to decision making, and suggested strategies for making such a transition more successful. The workshop was not intended to elicit consensus across participants or to provide a comprehensive survey, and there was no attempt to develop a set of recommendations. That said, there were a number of key observations that emerged from the 2 days of presentations and discussions that are summarized here and led to specific recommendations from the BOSC.

Key Observations from the Workshops

Research Outcomes Versus Outputs. A key aspect to any decision analysis technique is the development of an objective function against which the alternatives are considered. Consequently, the approach to evaluating the results of research (hence decisions on what research to pursue) should incorporate a consideration of outcomes rather than simply outputs. Participants noted that good decisions can have bad outcomes. There is a need to develop environmental metrics and indicators for evaluating decisions, where the indicators relate to specific objectives (e.g., at the highest level, this will always be the protection of human health and the environment). The goal is to identify good results with respect to policy outcomes being considered as opposed to simply good research. Consequently, the determination that the research decision was successful is based on the fact that the outcome indicator is on a better trajectory than it was prior to the research being conducted. Participants acknowledged the need to evaluate the benefits produced by Agency actions in terms of the environmental outcomes of policy relevance as opposed to simply the outputs of research. This is in keeping with the way all decision analysis questions are typically structured.

Use of Influence Diagrams. Influence diagrams represent an excellent first step to understanding determinants of a decision by developing a conceptual model of linkages and interrelationships across key aspects of the decision. Decision planners and analysts must communicate—as they are thinking about a research process—concerning the nature of the decision, the different elements, and how the linkages can be mapped. This allows analysts to better appreciate how their piece fits in, and what the specific uncertainties are that they face. Analysts and decision makers must agree on the completeness and complexity of the influence diagram. Different components emerge at different times, and will need to be added. Ultimately, this will assist in communicating decisions regarding funding and prioritization outward to interested stakeholders. In addition, influence diagrams ultimately will allow analysts to capture complex mathematical relationships using decision analysis methods to identify preferred solutions and alternatives in a decision-making context.

Key Personnel. Most individuals (within EPA or elsewhere), however, have had little formal decision analysis training; it is not typically part of core curricula in virtually any field. Working toward greater institutionalization of the use of decision analysis tools to support decision making is not to be taken lightly and cannot be accomplished without a significant concerted effort on the part of the Agency. Human resources come into play as there are differing roles across personalities and personnel; there have to be integrationalists and individuals who function in a liaison role and as facilitators along with focused technical people who supply the basic scientific information and data to feed into the model. Communication and facilitating communication across levels of decision making and decision implementation are required (the process of developing influence diagrams will assist with this) as well as focused training for key individuals.

Risk Management Training. There should be risk management training at all levels of the organization, starting with the highest level appointees. Scientists understand by definition that any analysis contains uncertainty and that uncertainty is not an excuse for inaction and should not preclude making decisions. This is not always understood, however, by everyone involved in the process, particularly those ultimately responsible for determining policy. When uncertainty is not presented and articulated (participants gave the example of economists, who generally do not discuss uncertainty, versus natural scientists, who cannot avoid it), there is the false impression that the analysis is more certain than it really is, and until decision makers, policy analysts, scientists, and even the general public become more comfortable and familiar with the language of uncertainty, decisions will suffer.

Reducing Uncertainties. Given specific decision objectives (presumably always related to protection of human health and the environment, but typically defined more precisely, e.g., what research is required to reduce the uncertainties in our understanding of regulating fine particulate matter [$PM_{2.5}$] and how should existing regulations be implemented), it is important to focus decisions on that goal and identify what information will reduce the uncertainties in achieving that goal. It is the uncertainties that make the decisions precarious that deserve the most emphasis with respect to conducting research to reduce those uncertainties. In particular, VOI techniques can be particularly useful for evaluating research options for reducing uncertainty. The value of reducing uncertainty is the expected value of information, which (analytically) depends on (a) the probability that a different decision will be made with the reduced uncertainty than would have been made with the original uncertainty, and (b) the improvement in the objective function (e.g., increase in net benefits) that results from making the new decision rather than the one that otherwise would have been made. It is necessary to identify the probabilities for the various decisions impacted by the research, and the probabilities for making alternate decisions. Therefore, VOI can be challenging for evaluating basic research because it can be difficult to quantitatively understand all the decisions that might be affected by the research.

Inter-, Multi-, and Trans-disciplinary. Participants spoke about the need to move beyond silo thinking and to unify disciplines, in keeping with the ongoing ORD transformation. For example, regulatory implementation and sustainability typically are considered separately, but they could be linked by incorporating life cycle assessment approaches within a decision analytic framework. Participants identified the desirability of integrative approaches. One of the key benefits of decision analytic approaches is providing an integrated framework for evaluating disparate pieces of information and data across disciplines.

Specific Recommendations

Use of decision analysis techniques to support research prioritization within ORD is feasible and recommended. The BOSC commends ORD on the initiative to provide a more transparent and accountable process for determining research priorities. Decision analysis techniques are a useful means of organizing and interpreting different kinds of information and data across stakeholders. There are many examples of models and techniques that can be used to support such an effort; indeed, the models may exceed our ability to use them effectively. The model or approach will not make the decision—it will merely inform the process by providing a framework for integrating data and stakeholder opinions, and provide a means for explicitly evaluating uncertainty. The tools, methods, approaches, and software available for incorporating decision analysis methods into the decision-making process have grown tremendously in the last 15 years, so much so that it is difficult, indeed unnecessarily prescriptive, to recommend one particular approach or piece of software[1,2]. Approaches range from spreadsheet-based tools (see Case Study #3) to sophisticated pieces of software that facilitate web-based stakeholder elicitation tools linked to optimization engines (see Case Study #1).

Leadership is necessary and required. Changes in the status quo and changes to the daily processes with which people are familiar require initiative and leadership at the highest levels. Support of the use of these techniques to assist in decision making and to optimize resources requires endorsement at the highest levels of ORD, followed by implementation in managed, concrete ways (e.g., by developing specific pilot cases across a spectrum of decisions; see below). In general, changing administrative procedures requires concrete leadership, particularly when these procedures are becoming technically more sophisticated and will require greater communication both laterally and vertically within ORD.

Develop pilot studies. Pilot studies provide concrete examples for staff to work through within a more narrowly defined context and will allow staff members to develop familiarity with the approaches and methods available to them. Rather than attempting wholesale fundamental changes in process, pilot studies, particularly when conducted concurrently to ongoing ORD transformational efforts, provide a means for staff to explore the utility of these methods going forward. Key areas that could form the basis for successful pilot studies include:

- ✧ <u>Evaluating Extramural Proposals</u>. There is an existing process for evaluating extramural research proposals, and this process can easily benefit from a decision analytic approach without any overt changes. Rather than having peer reviewers provide one overall recommendation, as is currently the case, peer reviewers should be asked to rate proposals using the existing criteria. This can be implemented using a spreadsheet-based approach as shown through Case Study #3 in this document. External and internal reviewers can enter their ratings directly into a spreadsheet, which then can be integrated to supply an overall ranking for the proposals. This is perhaps the easiest and most straightforward implementation of a decision analytic process, and could be accomplished with minimal training requirements.

- ✧ <u>Hydraulic Fracturing</u>. What are the research needs and potential actions required to protect against air and water pollution consequences from hydrofracking of shale deposits? Hydraulic fracturing (“fracking”) is the process of injecting fluid under pressure to facilitate the production of oil and natural gas. Depending on the fluid being used, there is increasing concern that drinking water aquifers and other water supplies may become contaminated during the process. There also is the question of whether EPA should be responsible for regulating fracking and what form that regulation might take. This represents an opportunity to use the tools of decision analysis to determine the optimum course of action, and what research should be pursued to reduce the uncertainty in the determination of how to proceed. This is a good candidate for a value of information type of analysis. There are benefits to fracking, but there is a probability of

[1] National Research Council. 1999. Decision Making in the U.S. Department of Energy’s Environmental Management Office of Science and Technology. Committee on Prioritization and Decision Making in the Department of Energy Office of Science and Technology, 230 pp.

[2] Youngblood RW, Arcieri WC, Faridi SC, Kdambi NP. 2003. Formal methods of decision analysis applied to prioritization of research and other topics. Prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-6833.

contaminating water supplies through the process. Potential contamination of the water supply has public health and other consequences, but there is uncertainty in our understanding of that process.

- Chicago Area Waterway System. Should the dams between the Chicago Area Waterway System be permanently closed to protect the Great Lakes against Asian Carp and other invasive species? There are benefits and limitations to consider in making this decision, and one way to evaluate the potential tradeoffs that might be made is through the use of multi-criteria decision analysis. In general, this process involves developing alternatives (there are other alternatives in addition to permanently closing the dams), developing criteria/objectives (to be maximized or minimized), and assigning weights to the criteria. Each of these steps requires a participatory process that includes all relevant stakeholders and agencies that have input to the decision. There are web-based software tools available for such a participatory process that allow for the application of rigorous methods in developing weights for each of the alternatives.

- Use of Biomonitoring Data to Inform Regulatory Strategies. How do we determine which of the chemicals that we collect with biomonitoring data need to be regulated? This is a question for which several different decision analytic methods might be applicable. One is a fairly standard decision tree format evaluating the probability of adverse outcomes together with some measure of population exposure (e.g., biomonitoring data) to target those chemicals with the highest potential for both exposure and toxicity. Biomonitoring data may reveal population exposures for which effects are poorly understood and VOI techniques can be used to identify those chemicals that should be the focus of further research.

- Gene-environment Interactions/Endocrine Disruptors/Pharmaceuticals. There is increasing emerging epidemiologic research on genetic/epigenetic alterations and disease outcomes, endocrine disruptors, and pharmaceuticals, but many unanswered questions remain. One approach to identifying what research to pursue would be to use a strategy similar to the one presented here for Case Study #1. This approach would use decision analytic tools to prioritize fruitful areas of research to pursue within a particular subject area.

- Integrated Risk Information System (IRIS). The IRIS program is tasked with developing toxicity factors for regulatory evaluations of environmental concentrations of chemicals. Decision analytic techniques could help inform this process in several ways. One way is to use VOI techniques to prioritize which chemicals require additional data or analysis before developing a toxicity factor. Decision trees and other hierarchical processes can be used when evaluating a single chemical to develop a more robust framework for weight-of-evidence analyses.

Engage staff in the effort. Imposing a process on staff and personnel is unlikely to be successful. Any significant changes to management procedures and the way in which decisions are made require a "cultural" as well as logistical shift within ORD. Start to cultivate the culture internally such that EPA staff recognizes the utility and usefulness of these approaches in making decisions, rather than as an imposition of an external process. A key aspect to this is that decision analysis methods, regardless of the specific approach or piece of software being used, are fundamentally concerned with communication. From a transparent, formalized process for engaging stakeholders and engaging in a deliberative process to developing criteria with which to evaluate specific courses of action or to prioritize research, decision analysis requires communication across management and levels of responsibility.

Resist the impulse to rely on one piece of software or an outside vendor or contractor to implement use of these techniques. There is no one-size-fits-all piece of software applicable across all levels of decision making. Likewise, it would be a mistake to rely solely on outside support through a contractor or vendor. Because the transition to a more defined and transparent process may be viewed by some as removing the ability to make decisions "just because," there may be resistance, and a contractor or outside vendor will be poorly suited to address the cultural aspects of implementation. Support must be available and internal.

Defining benefits. One of the most significant challenges across all decisions is defining the expected benefits. Many decision analysis techniques, including VOI, require quantifying benefits to estimate the value of research (e.g., what is the tradeoff between reducing uncertainty and the cost of reducing that uncertainty). A key aspect to that question is identifying how the ultimate decision might change given new information. That requires some estimate of the benefits of reducing uncertainty (e.g., if the decision does not change with the new information, then it is not worth reducing that particular uncertainty).

Introduction

ORD is tasked with identifying and carrying out a diverse research agenda with the goal of protecting human health and the environment. Identifying and evaluating research priorities would benefit from more structured approaches as are offered through the use of decision analysis methods. At the September 11-12, 2008 Board of Scientific Counselors (BOSC) Executive Committee Meeting, Dr. Fred Hauchman of EPA's Office of Science Policy (OSP) gave a presentation on using value of information (VOI)[3] techniques to prioritize research by more formally identifying the research that would most reduce uncertainty. Dr. Hauchman indicated that ORD would like to hear recommendations from the BOSC on the best way to proceed with respect to institutionalizing the use of VOI and other related techniques to support research prioritization and decision making within ORD. In response to this request, the BOSC formed a Decision Analysis Working Group to explore the use of decision analytic techniques for prioritizing research within the ORD context.

Table 1 provides a list of all BOSC recommendations from 2005 to 2008 that included a reference to clarifying or developing more explicit decision criteria that implicitly, if not directly, endorse a decision analytic approach to research program planning. Many of these comments and recommendations would be addressed through the use of a more formalized approach to developing research priorities.

[3] Value of information is a specific decision analytic technique that quantifies the value (in monetary or other terms) associated with reducing uncertainty prior to making a decision.

Table 1. Explicit Recommendations for Decision Analytic Approaches to Research Program Planning from BOSC Reports 2005 – 2008

Number	Recommendation	Program	Year Full/ Mid-Cycle
1	Discover how collaborative efforts can be pursued with greater effectiveness, and how certain historical program needs are addressed as programs sunset or are terminated.	Land	2006/2008
2	The MYP should address the current and future processes for replacing retiring expertise and developing new scientists with emphasis on emerging areas, increase support of university-based research to involve these stakeholders and train future generations of environmental researchers.	Land	2006/2008
3	Provide greater description of how criteria were used to prioritize needs and projects for both LTGs, but specifically for LTG 2.	Land	2006/2008
4	Incorporate input from outside groups (other government agencies, academia, industry, and other stakeholders), especially for future Land MYPs, and ensure that all valid scientific advice is heard and considered apart from policy issues.	Land	2006/2008
5	Describe or develop mechanisms for identifying mature research fields, emerging issues, and/or ensuring that the ORD-planned research is not duplicating efforts being conducted by other government or state agencies or by private industry. This could be guided by external peer review by experts drawn from universities, nongovernmental organizations (NGOs), state agencies, and private industries.	Land	2006/2008
6	Ensure that funding is directed toward areas in which large gains in understanding can be made through research. This involves favoring research areas that are new or emerging over mature areas of research.	Land	2006/2008
7	If there are recognized gaps associated with sunsetting or terminating programs, these could be prioritized for collaborative research efforts.	Land	2006/2008
8	Direction of research is influenced too strongly by external advisory groups (p. 8).	Human Health	2005/2007
9	Panel suggests a broadening of stakeholders involved in planning and prioritization of research (pp. 10, 26).	Human Health	2005/2007
10	Conceptual framework for research program needs to be better articulated.	Human Health	2005/2007
11	Program should specify specific goals and articulate a process for making decisions.	Human Health	2005/2007
12	The Program should explicitly take account of intra-Program and external synergies in research and in project evaluation, selection, design, and implementation.	Global Change	2006/2008
13	The Program should consider developing an explicit framework for priority setting and project selection to guide future Program activities; when articulated, such a framework would aid communication with its publics by making explicit those types of activities that were and were not candidates for action.	Global Change	2006/2008
14	The Program should engage diverse and multidisciplinary (“wise” as well as expert) external advisors to assist in formulating future Program direction and focus area projects. Given the very long-term nature of potential global change impacts (including consequences that occur across decades) such advisors should be tasked to address intergenerational concerns.	Global Change	2006/2008
15	The Program should take a more integrated and comprehensive systems approach when designing and implementing its activities across focus areas. In particular, it should consider integrating the Program’s water quality and ecosystems focus areas to a greater extent. Further, it should consider and take into account ancillary benefits and costs in evaluating its past and proposed activities.	Global Change	2006/2008
16	A more transparent approach to prioritizing research is recommended.	Water Quality	2006

Number	Recommendation	Program	Year Full/ Mid-Cycle
17	Prioritization based on impact, sensitivity, and uncertainty should be continued, but national versus regional significance, scaling according to anticipated completion of projects, and the relationship between existing and emerging topics also should be taken into account.	Water Quality	2006
18	When funds are not competitively awarded, the ERP appears to use a "best professional judgment" approach to allocate funds, coupled with a post-award assessment of the project's success. Based on the successful results associated with these projects, quality appears to have been maintained, although a more formal evaluation is warranted (p. 14).	Ecology	2005/2007
19	To identify key research gaps and to update the projects, the Subcommittee suggests reviews of individual projects by external scientists and stakeholders.	Ecology	2005/2007
20	The process for stakeholder engagement in research planning is unclear. In many cases, it appears to be ad hoc with fortuitous partnerships formed based on requests from entities or similar interests.	Ecology	2005/2007
21	Although numerous collaborators and stakeholders already are engaged, the process of identifying and engaging them could be more transparent.	Ecology	2005/2007
22	Funding decisions for any active intramural project undergo review by the Air Research Coordination Team.	Air	2005/2008
23	Cooperative agreements resulting in intramural collaboration receive internal peer review but are not open to an extensive outside review process. This may tend to perpetuate some research efforts that are past their prime and may leave the Agency open to concerns of "cronyism." ORD could consider a streamlined external review process that could make suggestions to improve the quality and/or timeliness of the cooperative venture.	Drinking Water	2005
24	ORD should evaluate strategies that could be implemented to encourage more cutting-edge research to identify and circumscribe issues, problems, and solutions that impact safe drinking water. One such strategy could be to invest greater resources in the STAR Program for an enlarged anticipatory research effort…. To anticipate new problems in drinking water contamination, treatment, distribution, and source water protection, the Agency should consider STAR solicitations that are somewhat more open ended. In particular, research contributing to the CCL process could benefit from greater levels of anticipatory/ exploratory research.	Drinking Water	2005
25	Clarify the criteria used to select new compounds for study, and expand the list of compounds under LTG 1C using the methods currently in use.	Safe Pesticides/ Safe Products	2007
26	Describe criteria for prioritization of future work and discuss how the additional projects meet the criteria.	Safe Pesticides/ Safe Products	2007
27	In order to maintain the high level of quality that is evident in the Human Health Risk Assessment (HHRA) work products, the Subcommittee strongly recommends that steps be taken to ensure the transparency of decisions made in the process of performing IRIS and PPRTV assessments and ISA assessments.	Human Health Risk Assess-ment	2008
28	The HHRA Program needs to consider information on the potential public health concern of various chemicals as it prioritizes them for IRIS or PPRTV review. It appears that some of this information is being provided by the program and regional offices, but it would be of value for the Program to make transparent the basis for its prioritization decisions for IRIS and PPRTVs.	Human Health Risk Assess--ment	2008
29	Mechanisms should be considered for retaining IRIS assessments older than 10 years that have not been updated, rather than allowing these assessments to expire and be removed from the IRIS database and Web site. One option is to simply annotate them as such.	Human Health Risk Assess-ment	2008

Number	Recommendation	Program	Year Full/ Mid-Cycle
30	LTG 1 metrics should be used to inform LTG 3 activities.	Sustainability	2008
31	Economics and other social dimensions should be incorporated as part of feedback loops of process or output evaluated decision-making.	Sustainability	2008
32	Engage state and local responders in identifying and prioritizing research.	Homeland Security	2008
33	Establish a program to develop and periodically evaluate the priorities for evaluating research goals.	Homeland Security	2008
34	Implement a mechanism to gauge the degree to which these priorities are heard and addressed.	Homeland Security	2008
35	Provide greater explanation in the MYP for the current priorities and how these may change.	Homeland Security	2008

Decision Analysis Workshop

To better understand how decision analysis techniques would be applicable and used more broadly for particular kinds of decisions, the BOSC decided to hold a workshop to hear from experts in the field and from those at other agencies who grapple with these issues on a daily basis. Consequently, the BOSC and the ORD National Risk Management Research Laboratory (NRMRL) organized a 2-day workshop on March 30–April 1, 2009, which was held at EPA's facility in Cincinnati, Ohio. The goal for the workshop was to identify and explore decision analysis methods and techniques for identifying and prioritizing research that could be developed and implemented within ORD. The workshop focused on the underlying science, engineering, and socioeconomic models and measures used to analyze alternative policies regarding environmental resources, including an explicit consideration of uncertainties. To this end, decision analysis models (extant or under development) with the potential to inform ORD's research and development planning and resource allocation were introduced through a series of presentations on the first day of the workshop. Discussions on the merits and limitations associated with the differing approaches and their appropriate application were encouraged. On the second day, a subset of participants discussed three case studies representing the types of decisions that ORD commonly faces and the available approaches that could best inform these categories of decisions.

Overview of Day 1

The health, wealth, and quality of individuals the world over is vitally dependent on the health of our shared natural resources. Ecosystems are complex, dynamic open systems whose intrinsic and extrinsic value often is not considered when making decisions that indirectly and/or directly impact a particular ecosystem. Reflecting the complexity surrounding environmental decisions, the economic and population growth patterns of the 20th century resulted in significant degradation of many ecosystems and ecosystem services. As ecosystems transform, biodiversity is lost, and federal, state, and local leaders are looking for methods with which to evaluate the future environmental impact of a particular decision relative to the services that the impacted ecosystem provides. ORD is uniquely positioned to provide decision makers with the information necessary to make adaptive management decisions that take into consideration environmental, economic, and social interrelations. This corresponds well with EPA's ongoing transition from a reactive organization—one that penalizes or regulates parties after the environmental damage or human exposure has occurred—to a proactive organization—one that incentivizes actions and decisions that improve environmental resources or minimize the impact of human activities on ecosystems. Such a shift will require ORD to confidently predict and communicate alternatives that capture the diversity of environmental, economic, and social dimensions with minimal uncertainty. This will drive a continuing need for more and better information resulting from ORD's environmental research.

Summary of Day 1

The agenda for the first day of the workshop is provided in Appendix A.

Presentations and videos are available on the Web at http://www.scgcorp.com/decision09/presentations.htm

Overview of Day 2

During the second day of the workshop, the necessary structure and components used in decision analysis were indentified within the context of three case studies representing the different kinds of decisions facing ORD that could benefit from more structured approaches.

In the face of shrinking buying power and increasing pressure to maximize research efficiency, ORD strives to leverage its research portfolio to maximize the affect on Agency decisions and ultimately on protection of human health and the environment. One of the most pressing tasks facing ORD is deciding how to evaluate strategic research options in a complex and uncertain decision-making environment. A primary objective in strategic planning is identifying new areas of opportunity and establishing research priorities to best meet current and future objectives under existing and expected constraints. The complexity and uncertainty surrounding such a prioritization makes it easy for decision makers to deliver a laundry list of all possible needs and problems, without defining which options are the most important. This tendency makes effective communication of research priorities difficult, if not impossible, and may give the perception that priorities are established in an opaque and subjective manner. While objective criteria may be, and typically are, used, a formalized record of the decision analysis process or established prioritization framework often is absent.

Participants for Day 2

Greg Biddinger, Exxon Mobil
Todd Bridges, U.S. Army Corps of Engineers
Michael Brydon, Simon Frasier University
Bob Clemen, Duke University
Tony Cox, Cox Associates
Heather Drumm, U.S. EPA
Adam Finkel, University of Pennsylvania Law School and University of Medicine & Dentistry of New Jersey, School of Public Health
Jonathan Garber, U.S. EPA
Iris Goodman, U.S. EPA
George Gray, former Assistant Administrator of ORD, U.S. EPA
Sally Gutierrez, U.S. EPA
Fred Hauchman, U.S. EPA
Bob Hetes, U.S. EPA
Timothy Johnson, U.S. EPA
Greg Kiker, University of Florida
Brian Kleinman, U.S. EPA
Dorothy Miller, AAAS Fellow
Mike Davis, U.S. EPA
Angela Page, U.S. EPA
Dale Pahl, U.S. EPA
Glenn Rice, U.S. EPA
Mitch Small, Carnegie-Mellon University
Cynthia Stahl, U.S. EPA Region 3
Katherine von Stackelberg (Moderator and BOSC representative), E Risk Sciences, LLP and the Harvard Center for Risk Analysis
Glenn Suter, U.S. EPA
Alexey Voinov, Program Coordinator at Chesapeake Research Consortium Community Modeling Program

Summary of Day 2

The discussions on Day 2 of the workshop were loosely centered on the three case studies, representing different levels of decision making. Case Study #1, the Ecological Research Program (ERP), involves making decisions at the strategic level over a 5 to 7 year timeframe. This level of decision making involves multi-year plans and setting priorities at a general level for research across ORD. Strategic research options provide directional guidance for all of the Laboratories, Centers, and Offices within ORD with activities supporting the National Research Program. The second case study, Nanoscale Titanium Dioxide for Water Treatment, is focused on identifying research priorities within a specific research topic. Finally, the third case study is an exercise in prioritizing proposals received in response to an extramural call for proposals.

Case Studies

The BOSC, with assistance from ORD, developed three case studies for discussion on Day 2 of the workshop. The decision contexts were presented to the Day 2 participants for their reaction and development input. The three case studies represent different levels of decision making that occur within the ORD context.

Case Study #1: Ecological Research Program

The objective of this case study is to explore decision analysis methods and approaches for prioritizing strategic research options using the Ecological Research Program (ERP) to provide a context. The questions considered through the exploration of this case study included:

- How do we prioritize ecological research needs and topics over the next 5 to 10 years?
- How should we formulate the question—how do we best frame the objective, alternatives, and criteria?
- What are the advantages and limitations of the different approaches for determining the appropriate allocation of resources across the identified research topics?
- This case study identifies the long-term goals (LTGs) of this research program as identified in 2008 with a corresponding resource allocation across those LTGs. What would be a more structured process for determining that resource allocation (it is not clear, currently, how those numbers were obtained—this is not to critique those numbers in particular but to identify strategies going forward that could provide a more robust justification)?
- Each LTG has a number of corresponding annual performance goals (APGs). Is there a more appropriate, structured approach for linking APGs with LTGs with respect to performance metrics? Do APGs become criteria for evaluating LTGs?

Workshop Participant Discussion

Workshop participants agreed that the level of decision making represented by this case study includes the most challenging aspects of a decision framework: multi-year goals with multiple objectives and multiple stakeholders resulting in information being generated over time and the necessity to make decisions now with repercussions downstream. Any model that is designed today will change over time, and selecting alternatives is really a portfolio choice rather than a simple prioritization. Participants pointed out that determining a research portfolio is not the same as prioritization per se. That said, developing a series of influence diagrams with underlying mathematical relationships based on decision analysis methods offers a modeling approach in which it is possible to track the provenance of the model and which explicitly identifies objectives, alternatives, and measures or criteria against which to evaluate the alternatives.

The participants discussed the perception that "sound science" implies, for some people, a degree of certainty that is, in general, not present. There is an implication that the science is more definitive than it actually is, particularly with respect to identifying policy alternatives. A key aspect to that is working with the decision uncertainty by developing what-if scenarios in the analysis of alternatives. How robust is the decision—the resource allocation across alternatives—to the assumptions? It is an important component of any decision problem and easily addressed through a sensitivity analysis of the results once the decision model is set up.

Participants were reluctant to categorize specific decision analysis methods or prescriptively identify approaches for particular situations. They agreed, however, that every decision problem, including this case study, follows the same general format:

- Define objectives/criteria.
- Identify alternatives.
- Map alternatives to objectives.
- Define measurement methods—what are the measures/criteria that relate the alternative to the objective (e.g., what constitutes success)?
- Quantitatively evaluate alternatives.

These can be stakeholder driven (as will be shown in this example) or for some decisions there are objective functions that can be used (e.g., the results of an external analysis or model such as a risk assessment). The most straightforward approach would be to structure the LTGs as objectives and APGs as specific alternatives to be evaluated. This could and should be refined as individuals become more familiar and comfortable with the process.

Case Study Development and Conclusions

Based on the comments from the workshop participants, we devised a simple example for resource allocation for the ecological research program using ExpertChoice software[4]. This software provides an intuitive web-based platform from which to include multiple stakeholders and to elicit stakeholder preferences in a consistent and transparent manner. The first step involved structuring the decision problem. For this example, we first identified each of the LTGs as specific objectives to be maximized (the criteria against which the alternatives are judged), and identified each of the APGs as potential alternatives to be funded, in keeping with the way in which this case study was initially structured.

Using the web-based stakeholder elicitation tool, we then assembled a stakeholder group. In an actual decision-making context, the stakeholder group would consist of all individuals with input into the final decision. The purpose of the stakeholder group is to map the importance of the various objectives with respect to the overall goal, and to map the importance of specific alternatives with respect to achieving objectives. ExpertChoice uses the analytical hierarchy process (AHP) as the underlying method for weighting the objectives. There are other methods

[4] www.expertchoice.com

available and some pieces of software provide more alternatives than others, but AHP is one that is widely used. This means that the stakeholders are asked to evaluate objectives in a pairwise fashion. For example, Figure 1 presents an example of a screen shot asking individual participants to evaluate the importance of LTGs “effective decision support” versus “national inventory, mapping, and monitoring.” Each participant answers a pairwise comparison across all objectives from which the program generates the weighting scheme for each objective. For the alternatives analysis, participants were asked to rate each alternative (APG) with respect to achieving the LTG. For example, for the LTG “human health and well-being,” participants were asked to rate each of the four APGs associated with that LTG on a scale ranging from not very much to outstanding. The rating scale can be specified by the user or can be based on several default scales included in most software.

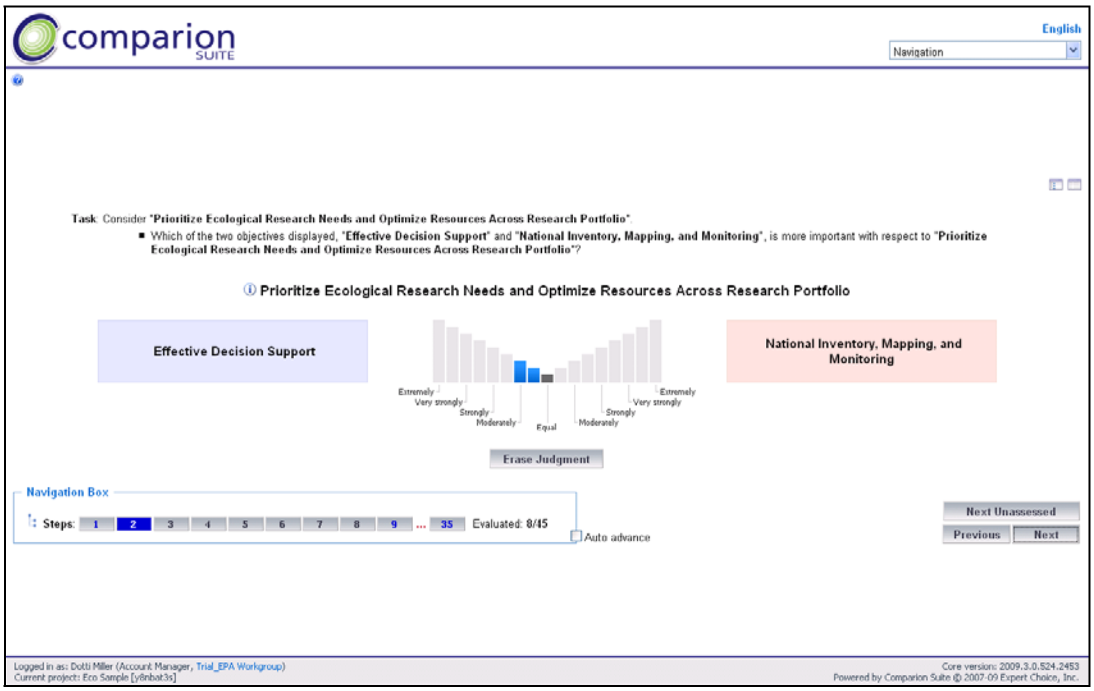

Figure 1. Comparion Screen Shot for Pairwise Objectives Analysis

The results then are compiled to identify weighting across objectives and alternatives as shown in Figure 2. Results can be evaluated by individual, combined, or by individual as compared to the combined results. In this example, “effective decision support” gets a weighting of 0.35 (of which “decision support platform” is weighted at 0.64), followed by “national inventory, mapping and modeling” (0.23), “nitrogen assessment” (0.13), “ecosystem assessments” (0.21), and finally “place based assessments” (0.07). With respect to the alternatives, the alternative with the highest weighting is “populate additional modules of the decision support platform…”

The next step is to incorporate the results of the stakeholder exercise with a resource allocation evaluation. In this step, the $69M available for the overall program is allocated across objectives and alternatives to identify funding priorities. Resources are allocated based on the weightings developed previously and subject to specific user-defined constraints, including budgets and dependencies (e.g., a particular alternative cannot be completed without significant input from another alternative and so on).

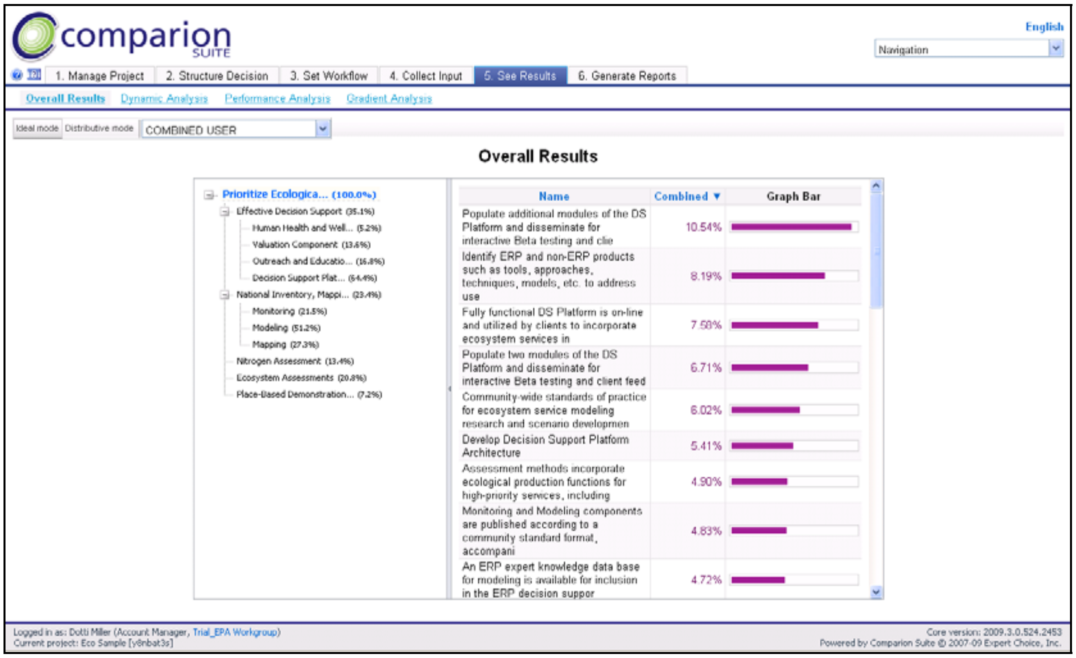

Figure 2. Comparion Screen Shot for Alternatives Rating

The results are presented in a report as shown in Figure 3. This report identifies each alternative, whether it should be funded or not, given the user-specified constraints and budgets, and required personnel requirements and constraints shown in this example as analysts, ecologists, and project managers. This brief example demonstrates the feasibility of going through this process to inform research prioritization at the highest, most strategic levels.

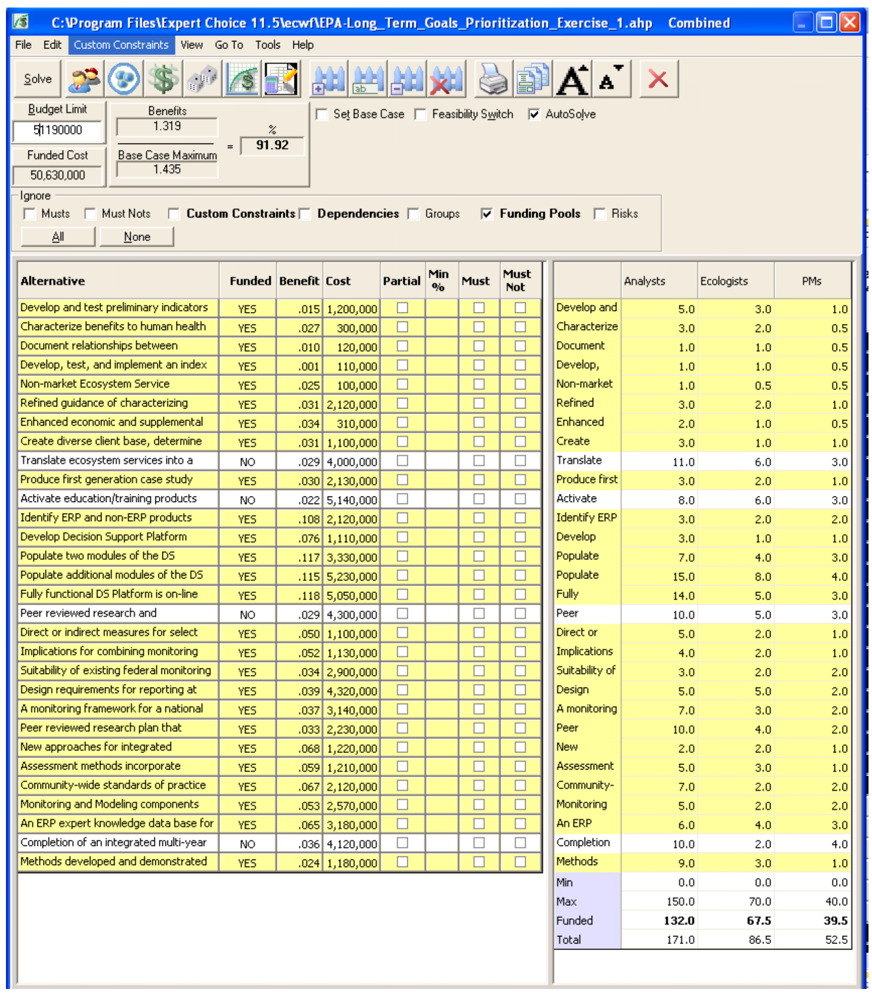

Figure 3. Comparion Screen Shot for Final Resource Allocation

Case Study #2: Nanoscale Titanium Dioxide for Water Treatment

The objective of this second case study is to explore decision analysis methods and approaches for prioritizing research alternatives within a specific research area or topic. (Note that this case study is an early draft that continues to undergo substantial revision and review. The goal is not to critique the case study in particular but to identify strategies going forward for structuring this type of decision.) The question "What do we need to know about nanoscale titanium dioxide (nano-TiO_2) in order to make a decision concerning its use for water treatment?" is quickly followed by "How do we prioritize the different options and make a decision about which research to pursue?" Listed throughout the case study and aggregated below are questions and areas for which basic information is still lacking (the research alternatives). These questions are intended to facilitate a comprehensive evaluation of the potential impacts and risks, both direct and indirect, potentially associated with the use of nano-TiO_2 for water treatment.

- ✧ How should these data gaps be prioritized to effectively make a decision with respect to potential risk concerning the use of nano-TiO_2 as a water treatment alternative?
- ✧ At this level of decision making, would VOI approaches be most appropriate?
- ✧ Nominal group theory has been proposed as a prioritization scheme. What are the advantages and limitations of this approach, and would other approaches be more effective?
- ✧ What software platforms exist to work from, and how difficult would it be to standardize across this level of decision making (e.g., what is the level of effort in adapting across specific contexts)?

Workshop Participant Discussion

This case study is a good candidate for a VOI analysis, assuming that the uncertainties can be quantitatively identified, and that it is possible to determine how the benefits of the final decision change given the new information. Workshop participants discussed the difficulty of being able to specifically identify ways in which decisions might change given a reduction in uncertainty for basic research. This is much more feasible for applied research.

Case Study Development and Conclusions

On September 29-30, 2009, the National Center for Environmental Assessment (NCEA) in EPA's Office of Research and Development held the "Nanomaterial Case Studies Workshop: Developing a Comprehensive Environmental Assessment Research Strategy for Nanoscale Titanium Dioxide." A point of departure for the meeting was the draft document *Nanomaterial Case Studies: Nanoscale Titanium Dioxide in Water Treatment and Topical Sunscreen*.[5] The objective in preparing this document and holding the workshop was to identify and prioritize research needed to support a comprehensive environmental assessment (CEA) of nano-TiO_2 as a first step in refining a strategic approach for nanomaterials risk assessment research. Because the complex and often unique properties of different nanomaterials make generalizations inadvisable, a "bottom-up" approach focusing on specific applications of a selected nanomaterial seemed more appropriate than attempting to consider nanomaterials as a general or abstract topic.

[5] U.S. Environmental Protection Agency. 2009. *Nanomaterial Case Studies: Nanoscale Titanium Dioxide in Water Treatment and Topical Sunscreen* (External Review Draft). Office of Research and Development, NCEA, Washington, DC, EPA/600/R-09/057, July. Available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=210206.

The case studies were constructed with a CEA framework, which is a holistic approach that incorporates a life-cycle perspective in the risk assessment paradigm.[6] The case studies, however, were not intended to be actual or even preliminary assessments, nor were they meant to provide a basis for risk management, regulatory, or policy decisions. Instead, the intent was to organize information on nanomaterials in a manner that would facilitate thinking about information gaps that would need to be filled to support future assessment efforts. Each chapter of the document listed several questions (almost 100 in all) that constituted information gaps or research needs. Readers were asked to consider the questions posed in the document and refine them or raise additional questions. It was hoped that the document and such questions would stimulate thinking about potential ecological and human health implications of the specific applications of the selected nanomaterials.

The workshop was designed to bring a variety of perspectives to bear on questions that would need to be addressed for assessment purposes. A multidisciplinary group of 50 participants was selected to balance across several categories of technical and stakeholder representation. Several of the invited participants had professional experience with nanotechnology, but many did not, and some participants were selected not as technical experts but as individuals with a broad familiarity with technical issues (e.g., journalists).

The workshop used a structured format known as Nominal Group Technique (NGT) to afford each participant an equitable opportunity to present his or her views for consideration by the group. A typical NGT workshop allows each person a limited amount of time in round-robin fashion to explain what he or she considers the highest or most important priority. A facilitator then assists the group in consolidating or grouping related issues, after which the group uses a multi-voting procedure to rank the top priorities. The EPA workshop modified this procedure by dividing the participants into two NGT groups of about 25 each to identify and rank needs. Subsequently, the two groups were brought together in a plenary session to consolidate their respective priorities and vote to determine the top-ranked priorities. Then, smaller groups of about five persons each were created to write 3- to 5-page narratives on each of the top-ranked priority needs. Among other things, the narratives were supposed to explain why the particular issue was important in relation to supporting CEA and how it was related to other information or research needs. In addition, the writers were asked to consider whether the need was specific to a particular application of nano-TiO_2, to nano-TiO_2 without regard to its application, or to nanomaterials in general. These narratives were summarized in informal presentations to the plenary group, and the group was encouraged to suggest additional thoughts about possible linkages between various information needs.

The results of the plenary voting can be summarized in terms of prominent themes revolving around needs for characterizing physicochemical properties, ecological and human health effects, and exposure:

Physicochemical characterization
- Identify key properties
- Develop/apply methods
- Relate to life cycle stages, fate & transport, matrices, exposure, effects

Effects characterization (ecotoxicity, human health)
- Standardize/harmonize test protocols, acute/chronic

[6] **Error! Main Document Only.**Davis JM. 2007. How to assess the risks of nanotechnology: learning from past experience. *Journal of Nanoscience and Nanotechnology* 7:402-409.

Reference materials
Mechanisms

Exposure characterization

Sources/life cycle stages, pathways, routes
Typical and atypical (high-end)
Environmental spatial/temporal distribution, background levels, natural vs. anthropogenic, bioaccumulation

A more detailed report describing the rationale for the case studies workshop and how it was designed and conducted, along with outcomes from the process, will be provided at a later date.

Case Study #3: Extramural Research: Development and Evaluation of Innovative Water Infrastructure Sustainability Approaches

This case study is an example of prioritization and resource allocation of extramural funds. In this case, it is an evaluation of proposals submitted in response to a Request for Applications (RFA) to support the Drinking Water Research Program (DWRP). It included a description of the peer review process currently used to evaluate proposals; however, the peer review process in and of itself does not prioritize proposals, and it is likely that additional information (e.g., availability of funding and funds requested, feasibility, etc.) needs to be traded off in reaching a final decision on which proposals will be funded and which will not. For example, if there are five proposals receiving a rating of excellent through the peer review process but funding them all would exceed budgetary constraints, what are appropriate and transparent additional criteria to apply in evaluating the proposals? To frame this case study more concretely, the (hypothetical) submissions for the Development and Evaluation of Innovative Water Infrastructure Sustainability Approaches RFA were evaluated against a set of criteria.

- What is the appropriate method for prioritizing these proposals?
- What would it take to develop a standardized format for doing this (e.g., identifying evaluation criteria and so on)?
- How does one structure evaluation criteria such that truly innovative "transformative" research is not penalized (e.g., the probability of "success" is difficult to quantify, and success in this case could lead to transformations in the way the problem is addressed and lead to a major breakthrough)?
- What software platforms exist to work from?

Workshop Participant Discussion

Workshop participants viewed this case study as the most straightforward of the three. Several participants indicated that a model could be developed in Excel, in a format similar to one that would be developed for evaluating investment decisions. The difficulty, it was acknowledged, lies in defining the benefits. In general, an investment evaluation would require an estimate of the net present value of revenue associated with the decision, while investing in research is not that straightforward. For some methods, a probability of success could be used, and this probability could be elicited from the peer review panel.

Case Study Development and Conclusions

There is an existing peer review process for evaluating proposals. Individual external peer review panel members are asked to consider the merit of an application based on the criteria below (listed in descending order of importance):

1. Research Proposal (criteria "1a" through "1f" are essentially equal):
    a. The originality and creativity of the proposed research, the appropriateness and adequacy of the proposed research methods, and the Quality Assurance Statement.
    b. Practical and technically defensible approach that can be performed within the proposed time period.
    c. Research contributes to scientific knowledge in the topic area.
    d. Projected benefits of the proposed activity to society, such as improving the environment or human health.
    e. The results are disseminated broadly to enhance scientific and technological understanding. For example, the software developed under this solicitation could be placed into the public domain.
    f. The proposal is well prepared with supportive information that is self-explanatory or understandable.
2. Investigators: The qualifications of the Principal Investigator(s) and other key personnel, including research training, demonstrated knowledge of pertinent literature, experience, and publication records. All key personnel must make a significant time commitment to the project.
3. Responsiveness: The responsiveness of the proposal to the research needs identified for the research area. The proposal adequately addresses the objectives and special considerations specified by the RFA.
4. Facilities and Equipment: The availability and/or adequacy of the facilities and equipment proposed for the project. Note any deficiencies that may interfere with the successful completion of the research.

Budget: Although budget information does not reflect on the application's scientific merit, the reviewers are asked to provide their view on the appropriateness and/or adequacy of the proposed budget and its implications for the potential success of the proposed research. Input on requested equipment is of particular interest.

Peer reviewers then are asked to provide an overall rating that reflects their individual ratings for each of these criteria. It would facilitate analysis of results for peer reviewers to rate each category individually, instead of arriving at an overall rating themselves. For example, Table 2 provides a list of potential criteria and example ratings from three peer reviewers.

Table 2. Example of Criteria and Ratings

For each proposal, rate the following criteria on a scale of 1 to 5, where 1 is best and 5 is worst.			
Criteria	**Peer Reviewer 1**	**Peer Reviewer 2**	**Peer Reviewer 3**
Originality	1	2	1

For each proposal, rate the following criteria on a scale of 1 to 5, where 1 is best and 5 is worst.			
Criteria	**Peer Reviewer 1**	**Peer Reviewer 2**	**Peer Reviewer 3**
Creativity	2	3	4
Appropriateness	2	3	5
Adequacy	1	2	1
QA/QC statement	4	3	3
Practical and technically defensible approach	2	3	2
Research contributes to scientific knowledge	3	4	3
Projected benefits of the proposed activity to society	2	1	3
Results are disseminated broadly	1	1	1
Proposal is well-prepared	2	2	1
Qualifications of PI	2	2	3
Qualifications of key personnel	1	1	1
Responsiveness	2	3	2
Appropriate facilities and equipment	1	2	1

The peer reviewers can be directed as precisely as necessary to evaluate the results. For example, every proposal is responding to a particular topic, and sometimes those topics are somewhat general in nature, and other times they are very specific. Peer reviewers can receive guidance on how to interpret the criteria (e.g., the proposal must address specific issues to be considered responsive, such as a specific focus on aging infrastructure, for example).

Cost can be included directly in the analysis. Internal peer reviewers also can fill out a matrix such as this, and internal comments could be weighted differently from external review comments. This analysis can be conducted using a spreadsheet model, but a key aspect to doing this is being able to define the expected value of the benefit of the outcome, if not in monetary values (making the analysis analogous to an investment decision), then as a probability of success. This is the single most difficult aspect of the analysis. One could ask the peer reviewers for a probability of success, and use that in the analysis as the measure of probability of success. Monetizing the outcome, analogous to an actual investment decision, is more difficult.

We developed an example for this case study using a simple spreadsheet format in Excel. In this spreadsheet, external peer reviewers are asked to rate a series of questions based on the table shown above. These scores then are linked and averaged in a master spreadsheet for which hypothetical results are shown in Figure 4. Internal and external evaluations can be combined and weighted in different ways using this format. As mentioned above, the most challenging issue faced through the use of this format is defining the expected benefit (ideally in monetary terms) with which to formally estimate a net expected return on investment.

Figure 4. Example Spreadsheet Approach for Selecting Extramural Proposals

Funds Available ($M)	30							
		Evaluator Weights 0.4	0.6					
Proposal Number	Funding Request ($M)	External Evaluator Score (return)	Internal Evaluator Score (return)	Total Score	Cumulative Investment ($M)	Bang per buck	Merit Prioritized Funded? 1=yes 0=no	Merit Optimized Funded? 1=yes 0=no
B	1.31	1.00	1.00	1.00	1.31	0.76	1	1
U	1.19	0.90	0.96	0.94	2.50	0.76	1	1
P	2.10	0.53	0.90	0.75	4.60	0.25	1	1
J	1.66	0.50	0.88	0.73	6.26	0.30	1	1
N	9.67	0.79	0.61	0.68	15.93	0.08	1	0
O	1.03	0.77	0.54	0.63	16.96	0.75	1	1
S	4.18	0.88	0.41	0.60	21.14	0.21	1	1
Y	6.53	0.21	0.79	0.56	27.67	0.03	1	0
G	4.26	0.53	0.53	0.53	31.93	0.12	0	1
R	1.51	0.15	0.77	0.52	33.44	0.10	0	0
H	5.14	0.06	0.82	0.52	38.58	0.01	0	0
L	3.01	0.96	0.19	0.50	41.59	0.32	0	1
Q	9.55	0.78	0.24	0.46	51.14	0.08	0	0
V	1.14	0.41	0.44	0.43	52.28	0.36	0	1
I	1.04	0.47	0.40	0.43	53.32	0.45	0	1
A	9.11	0.25	0.50	0.40	62.43	0.03	0	0
F	1.82	0.19	0.53	0.39	64.25	0.10	0	1
X	8.12	0.82	0.04	0.35	72.37	0.10	0	0
C	3.89	0.14	0.49	0.35	76.26	0.04	0	0
M	1.44	0.61	0.15	0.33	77.70	0.42	0	1
K	6.27	0.24	0.38	0.32	83.97	0.04	0	0
T	8.05	0.44	0.21	0.30	92.02	0.05	0	0
D	3.67	0.38	0.14	0.24	95.69	0.10	0	0
E	4.55	0.49	0.06	0.23	100.24	0.11	0	1
W	1.15	0.20	0.20	0.20	101.39	0.17	0	1
Z	6.20	0.04	0.25	0.17	107.59	0.01	0	0
						Total Investment	27.67	29.88
						Merit Score	5.58	8.44

Conclusions, Observations, and Recommendations

Workshop participants agreed that more structured approaches to decision making, particularly with respect to prioritizing research, is a laudable goal and should be encouraged. It is not, however, an effort that can be conducted half-heartedly, or that will occur overnight. Workshop participants agreed that a focused effort to develop internal resources and to identify key individuals to coordinate the effort would begin the process of cultural shift required to successfully implement the transition to a more formalized decision-making procedure. Participants were reluctant to categorize methods and pieces of software for specific kinds of decisions and cautioned against a "cookie-cutter," prescriptive approach. The workshop participants also discussed the difficulties in transitioning an institution to a more structured approach to decision making. The workshop was not intended to be a consensus workshop or a comprehensive survey and there was no attempt to develop a set of recommendations. That said, there were a number of key observations that emerged from the 2 days of presentations and discussions.

Key Observations from the Workshops

Research outcomes versus outputs. A key aspect to any decision analysis technique is the development of an objective function against which the alternatives are considered. Consequently, the approach to evaluating the results of research (hence decisions on which research to pursue) should incorporate a consideration of outcomes rather than simply outputs. Participants noted that good decisions can have bad outcomes. There is a need to develop environmental metrics and indicators for evaluating decisions, where the indicators relate to specific objectives (e.g., at the highest level, this will always be the protection of human health and the environment). The goal is to identify good results with respect to policy outcomes being considered as opposed to simply good research. Consequently, the determination that the research decision was successful is based on the fact that the outcome indicator is on a better trajectory than it was prior to the research being conducted. Participants acknowledged the need to evaluate the benefits produced by Agency actions in terms of the environmental outcomes of policy relevance as opposed to simply the outputs of research. This is in keeping with the way all decision analysis questions are typically structured.

Use of influence diagrams. Influence diagrams represent an excellent first step to understanding determinants of a decision by developing a conceptual model of linkages and interrelationships across key aspects of the decision. Decision planners and analysts must communicate—as they are thinking about a research process—concerning the nature of the decision, the different elements, and how the linkages can be mapped. This allows analysts to better appreciate how their piece fits in, and what the specific uncertainties are that they face. Analysts and decision makers must agree on the completeness and complexity of the influence diagram. Different components emerge at different times, and will need to be added. Influence diagrams will assist in communicating decisions regarding funding and prioritization outward to interested stakeholders. In addition, influence diagrams ultimately allow analysts to capture complex mathematical relationships using decision analysis methods to identify preferred solutions and alternatives in a decision-making context.

Key personnel. Most individuals (within EPA and elsewhere) have had little formal decision analysis training because it is not typically part of core curricula in virtually any field. Working toward greater institutionalization of the use of decision analysis tools to support decision making is not to be taken lightly and cannot be accomplished without a significant concerted effort on the part of the Agency. Human resources come into play as there are differing roles across personalities and personnel; there have to be integrationalists and individuals who function in a liaison role as well as facilitators along with focused technical people who supply the basic scientific information and data to feed into the model. Communication and facilitating communication across levels of decision making and decision implementation are required (the process of developing influence diagrams will assist with that) as well as focused training for key individuals.

Risk management training. There should be risk management training at all levels, starting with the highest level appointees. Scientists understand by definition that any analysis contains uncertainty and that uncertainty is not an excuse for inaction and should not preclude making decisions. This is not always understood, however, by everyone involved in the process, particularly those ultimately responsible for determining policy. When uncertainty is not presented and articulated (participants gave the example of economists, who generally do not discuss uncertainty, versus natural scientists, who cannot avoid it), there is the false impression that the analysis is more certain than it really is, and until decision makers, policy analysts, scientists, and even the general public become more comfortable and familiar with the language of uncertainty, decisions will suffer.

Reducing uncertainties. Given specific decision objectives (presumably always related to protection of human health and the environment, but typically defined more precisely, e.g., what research is required to reduce the uncertainties in our understanding of regulating $PM_{2.5}$ and how should existing regulations be implemented?), it is important to focus decisions on that goal and identify what information will reduce the uncertainties in achieving that goal. It is the uncertainties that make the decisions precarious that deserve the most emphasis with respect to conducting research to reduce those uncertainties. In particular, VOI techniques can be particularly useful for evaluating research options for reducing uncertainty. The value of reducing uncertainty is the expected VOI, which (analytically) depends on (a) the probability that a different decision will be made with the reduced uncertainty than would have been made with the original uncertainty, and (b) the improvement in the objective function (e.g., increase in net benefits) that results from choosing the new decision rather than the one that otherwise would have been selected. It is necessary to identify the probabilities for the various decisions impacted by the research, and the probabilities for making alternate decisions. Therefore, VOI can be challenging for evaluating basic research because it can be difficult to quantitatively understand all the decisions that might be affected by the research.

Inter-, multi-, and trans-disciplinary. Participants spoke about the need to move beyond silo thinking and to unify disciplines, in keeping with the ongoing ORD transformation. For example, regulatory implementation and sustainability are typically considered separately, but they could be linked by incorporating life cycle assessment approaches within a decision analytic framework. Participants identified the desirability of integrative approaches. One of the key benefits of decision analytic approaches is providing an integrated framework for evaluating disparate pieces of information and data across disciplines.

Recommendations

"Decision analysis" can be an intimidating term for some people. The emphasis should be on the process for making decisions, and the tools and approaches that allow key stakeholders to get involved and explicitly resolve potential differences and discrepancies. Influence diagrams and conceptual models are key tools for identifying relationships and linkages across components of a decision. Resource allocation with respect to identifying research priorities is a multi-objective, multi-stakeholder process that changes over time given new information, constraints, budgets, political priorities, and technical feasibility. There is no one particular solution in terms of software or methods. There are, however, a host of resources available and precedents at other agencies (e.g., the National Aeronautics and Space Administration and U.S. Army Corps of Engineers) to make the cultural transition easier.

Use of decision analysis techniques to support research prioritization within ORD is feasible and recommended. The BOSC commends ORD on its initiative to provide a more transparent and accountable process for determining research priorities. Decision analysis techniques are a useful means of organizing and interpreting different kinds of information and data across stakeholders. There are many examples of models and techniques that can be used to support such an effort; indeed, the models may exceed our ability to use them effectively. The model or approach will not make the decision—it will merely inform the process by providing a framework for integrating data and stakeholder opinions, and provide a means for explicitly evaluating uncertainty. The tools, methods, approaches, and software available for incorporating decision analysis methods into the decision-making process have grown tremendously in the last 15 years, so much so that it is difficult, indeed unnecessarily prescriptive, to recommend one particular approach or piece of software[7,8]. Approaches range from spreadsheet-based tools (see

[7] National Research Council. 1999. Decision Making in the U.S. Department of Energy's Environmental Management Office of Science and Technology. Committee on Prioritization and Decision Making in the Department of Energy Office of Science and Technology, 230 pp.

[8] Youngblood RW, Arcieri WC, Faridi SC, Kdambi NP. 2003. Formal methods of decision analysis applied to prioritization of research and other topics. Prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-6833.

Case Study #3) to sophisticated pieces of software that facilitate web-based stakeholder elicitation tools linked to optimization engines (see Case Study #1).

Leadership is necessary and required. Changes in the status quo and changes to the daily processes with which people are familiar require initiative and leadership at the highest levels. Support of the use of these techniques to assist in decision making and to optimize resources requires endorsement at the highest levels of ORD, followed by implementation in managed, concrete ways (e.g., by developing specific pilot cases across a spectrum of decisions; see below). In general, changing administrative procedures requires concrete leadership, particularly when these procedures are becoming technically more sophisticated and will require greater communication both laterally and vertically within ORD.

Develop pilot studies. Pilot studies provide concrete examples for staff to work through within a more narrowly defined context and will allow staff to develop familiarity with the approaches and methods available to them. Rather than attempting wholesale fundamental changes in process, pilot studies—particularly when conducted concurrently to ongoing ORD transformational efforts—provide a means for staff to explore the utility of these methods going forward. Key areas that could form the basis for successful pilot studies include:

- <u>Evaluating Extramural Proposals</u>. There is an existing process for evaluating extramural research proposals, and this process can easily benefit from a decision analytic approach without any overt changes. Rather than having peer reviewers provide one overall recommendation, as currently is the case, peer reviewers should be asked to rate proposals using the existing criteria. This can be implemented using a spreadsheet-based approach as shown through Case Study #3 in this document. External and internal reviewers can enter their ratings directly into a spreadsheet, which then can be integrated to supply an overall ranking for the proposals. This is perhaps the easiest and most straightforward implementation of a decision analytic process, and could be accomplished with minimal training requirements.

- <u>Hydraulic Fracturing</u>. What are the research needs and potential actions required to protect against air and water pollution consequences from hydrofracking of shale deposits? Hydraulic fracturing ("fracking") is the process of injecting fluid under pressure to facilitate the production of oil and natural gas. Depending on the fluid being used, there is increasing concern that drinking water aquifers and other water supplies may become contaminated during the process. There also is the question of whether EPA should be responsible for regulating fracking and what form that regulation might take. This represents an opportunity to use the tools of decision analysis to determine the optimum course of action, and what research should be pursued to reduce the uncertainty in the determination of how to proceed. This is a good candidate for a VOI type of analysis. There are benefits to fracking, but there is a probability of contaminating water supplies through the process. Potential contamination of the water supply has public health and other consequences, but there is uncertainty in our understanding of that process.

- <u>Chicago Area Waterway System</u>. Should the dams between the Chicago Area Waterway System be permanently closed to protect the Great Lakes against Asian Carp and other invasive species? There are benefits and limitations to consider in making this decision, and one way to evaluate the potential tradeoffs that might be made is through the use of multi-criteria decision analysis. In general, this process involves developing alternatives (there are other alternatives in addition to permanently closing the dams), developing criteria/objectives (to be maximized or minimized), and assigning weights to the criteria. Each of these steps requires a participatory process that includes all relevant stakeholders and agencies that have input to the decision. There are web-based software tools available for such a participatory process that allow for the application of rigorous methods in developing weights for each of the alternatives.

- ✧ Use of Biomonitoring Data to Inform Regulatory Strategies. How do we determine which of the chemicals that we collect with biomonitoring data need to be regulated? This is a question for which several different decision analytic methods might be applicable. One is a fairly standard decision tree format evaluating the probability of adverse outcomes together with some measure of population exposure (e.g., biomonitoring data) to target those chemicals with the highest potential for both exposure and toxicity. Biomonitoring data may reveal population exposures for which effects are poorly understood and VOI techniques can be used to identify those chemicals that should be the focus of further research.

- ✧ Gene-environment Interactions/Endocrine Disruptors/Pharmaceuticals. There is increasing emerging epidemiologic research on genetic/epigenetic alterations and disease outcomes, endocrine disruptors, and pharmaceuticals, but many unanswered questions remain. One approach to identifying what research to pursue would be to use a strategy similar to the one presented here for Case Study #1. This approach would use decision analytic tools to prioritize fruitful areas of research to pursue within a particular subject area.

- ✧ Integrated Risk Information System (IRIS). The IRIS program is tasked with developing toxicity factors for regulatory evaluations of environmental concentrations of chemicals. Decision analytic techniques could help inform this process in several ways. One way is to use VOI techniques to prioritize which chemicals require additional data or analysis before developing a toxicity factor. Decision trees and other hierarchical processes can be used when evaluating a single chemical to develop a more robust framework for weight-of-evidence analyses.

Engage staff in the effort. Imposing a process on staff and personnel is unlikely to be successful. Any significant changes to management procedures and the way in which decisions are made require a "cultural" as well as logistical shift within ORD. Start to cultivate the culture internally such that EPA staff recognizes the utility and usefulness of these approaches in making decisions, rather than as an imposition of an external process. A key aspect to this is that decision analysis methods, regardless of the specific approach or piece of software being used, are fundamentally concerned with communication. From a transparent, formalized process for engaging stakeholders and engaging in a deliberative process to developing criteria with which to evaluate specific courses of action or to prioritize research, decision analysis requires communication across management and levels of responsibility.

Resist the impulse to rely on one piece of software or an outside vendor or contractor to implement use of these techniques. There is no one-size-fits-all piece of software applicable across all levels of decision making. Likewise, it would be a mistake to rely solely on outside support through a contractor or vendor. Because the transition to a more defined and transparent process may be viewed by some as removing the ability to make decisions "just because," there may be resistance, and a contractor or outside vendor will be poorly suited to address the cultural aspects of implementation. Support must be available and internal.

Defining benefits. One of the most significant challenges across all decisions is defining the expected benefits. Many decision analysis techniques, including VOI, require quantifying benefits to estimate the value of research (e.g., what is the tradeoff between reducing uncertainty and the cost of reducing that uncertainty). A key aspect to that question is identifying how the ultimate decision might change given new information. That requires some estimate of the benefits of reducing uncertainty (e.g., if the decision does not change with the new information, then it is not worth reducing that particular uncertainty).

Appendices

Appendix A: Agenda for Day One

7:30 a.m. – 8:00 a.m.	**Registration**
8:00 a.m. – 8:10 a.m.	**Introduction** *Sally Gutierrez - Director, National Risk Management Research Laboratory (NRMRL), Office of Research and Development (ORD), EPA*
8:10 a.m. – 8:30 a.m.	**Keynote**, Characterizing Uncertainty for Sound Decisions *George Gray – Former Assistant Administrator EPA/ORD and EPA Science Advisor, 2005–2009*
8:30 a.m. – 9:00 a.m.	Characterizing Social Preferences for Health and Environmental Risks *James Hammitt – Professor of Economics and Decision Sciences, Harvard School of Public Health*
9:00 a.m. – 9:30 a.m.	The Value of Technical Information in Environmental Decision Making Processes *Mitchell Small – H. John Heinz III Professor of Environmental Engineering, Carnegie Mellon University*
9:30 a.m. – 10:00 a.m.	**Break**
10:00 a.m. – 10:30 a.m.	Systemic Risk Management Through Analytic Deliberation: A European Perspective *Piet Sellke – University of Stuttgart*
10:30 a.m. – 11:00 a.m.	Understanding and Engineering the Complexity of Urban Systems *John Crittenden – Director of the Brook Byers Institute for Sustainable Systems, Georgia Institute of Technology*
11:00 a.m. – 11:30 a.m.	Integrating Economic and Ecological Models for Environmental Decision Making: A Participatory, Community-based Approach *Alexey Voinov – Chesapeake Research Consortium*
11:30 a.m. – 1:00 p.m.	**Lunch**
1:00 p.m. – 1:30 p.m.	Decision Analysis Under Uncertainty: A Systems Analysis Perspective *Urmila Diwekar – President, Vishwamitra Research Institute*

1:30 p.m. – 2:00 p.m.	Environmental Assessments for Better Environmental Decisions *Glenn Suter – EPA/ORD National Center for Environmental Assessment*
2:00 p.m. – 2:30 p.m.	Development, Assessment, and Uncertainty for Sustainable Consumer Products *Annie Weisbrod – Procter and Gamble, Product Safety and Regulatory Affairs – Sustainability*
2:30 p.m. – 3:00 p.m.	Informing Decisions in View of Diverse Objectives, Risks, and Values *Todd Bridges – Senior Research Scientist, U.S. Engineer Research and Development Center*
3:00 p.m. – 3:30 p.m.	**Break**
3:30 p.m. – 4:00 p.m.	Linking Science to Decision Making at the U.S. EPA Region III *Cynthia Stahl - Office of Environmental Information and Analysis, Environmental Assessment and Innovation Division, EPA Region 3*
4:00 p.m. – 4:30 p.m.	Decision Support Framework (DSF) for Planning Land and Resource Use To Sustainably Maintain Healthy Ecosystem Services and Communities *Ann Vega – Revitalization Research Program Manager, Land Remediation and Pollution Control Division, Remediation and Redevelopment Branch, EPA*
4:30 p.m. – 5:00 p.m.	**Session Wrap-Up** *George Gray, Mitchell Small, and James Hammitt*
5:00 p.m. – 5:10 p.m.	**Closing Remarks** *Herbert L. Fredrickson, Associate Director for Ecology, NRMRL, EPA*
5:10 p.m.	**Adjournment**

Appendix B: General Charge Questions for Day 2 Panel Discussion

Day 2 of the workshop is organized around three case studies to guide the discussions. These represent the kinds of decisions facing ORD that would benefit from a more structured decision-making process. The goal is not to critique these documents or to focus too closely on the specific subject matter, but rather to use them as a context and basis for discussion. To that end, here are a few general charge questions to keep in mind in reviewing the case studies (more specific questions are provided in the "purpose" section of each individual document).

1. EPA has a particular process for structuring research priorities (see Figure B-1), including developing multi-year plans (MYPs) that describe long-term goals (LTGs); annual performance goals (APGs) against which to measure progress in achieving long-term goals, and finally the allocation on an annual basis of dollars at the program and laboratory level. What is the best approach for adapting the existing structure within a decision analysis context (e.g., alternatives, objectives, evaluation criteria, constraints)? Can LTGs and APGs be formulated as alternatives and objectives? Or should the terminology be redefined?
2. What are the specific evaluation criteria, inputs, and other pieces of information necessary to structure the decision? What do you need to know in order to set up the decision framework?
3. Clearly it is not possible to have a "one size fits all" piece of software off the shelf that can simply be modified for a specific context. That said, is it possible to develop a generalized framework that can be adapted from case to case (at each decision level)?
4. What adaptable software exists or is this likely a "from scratch" endeavor?
5. Are there preferred prioritization schemes, and if so, are these better suited to particular decision levels? For example, specifically in the context of the nanotechnology case study, nominal group theory has been proposed. Is that appropriate? Are there "better" approaches to use?
6. Regardless of the decision level, making decisions about research priorities obviously requires technical knowledge and familiarity with the subject matter. What other expertise is necessary or useful for setting up a more structured framework? Is it possible to do this with existing personnel and "training," or will this require trained decision analysts in order to institutionalize the process?

Figure B-1. Elements of the Multi-Year Plan (MYP) Process