Integrated Environmental Assessment and Management — Volume 4, Number 4—pp. 478–485

A Theory of Practice for Environmental Assessment

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(Received 13 January 2008; Accepted 9 June 2008)

EDITOR'S NOTE:
This paper was presented at the SETAC North America Annual Meeting in Milwaukee, Wisconsin, on 12 November 2007.

ABSTRACT

Environmental assessment practices have not been as successful as they should be. We believe that this is in part because environmental assessors lack a clear and useful set of principles—that is, a theory of practice. We propose a theory that derives 19 principles from 3 axioms: 1) assessments inform environmental management decisions, 2) assessments are science based, and 3) management decisions accommodate multiple goals and constraints. The 1st axiom leads to principles that change the focus from good assessments to good decisions. The 2nd focuses assessments on the scientific needs of the decision maker rather than making policy judgments or consensus building. The 3rd axiom leads to integration across disciplines, scales, and types of evidence. This theory of assessment practice implies the need for a new framework for environmental assessment that is more integrative than existing frameworks and more focused on making decisions that resolve environmental problems. We believe that this theory of environmental assessment can lead to clear assessment practices that compel beneficial and confident environmental management.

Keywords: Environmental assessment Causality Risk assessment Environmental epidemiology Ecoepidemiology

Whilst a few persons, by extraordinary genius or, by the accidental acquisition of a good set of intellectual habits, may profitably work without pre-set principles, the bulk of mankind require either to understand the theory of what they are doing, or to have rules laid down for them by those who have understood the theory.

John Stewart Mill

INTRODUCTION

Environmental assessment is dependent on scientific knowledge and theories. But, as Mill indicated in the passage quoted above, we need theories of practice as much as scientific theories. Although theories of business management, theories of education, theories of warfare, and other theories of practice are common, we know of no explicit theory of scientific practice in environmental assessment. Holder (2004) said of environmental assessment that "it is currently an undertheorized phenomenon." Therefore, we present this theory formally in terms of axioms (basic assumptions) and principles (derived general precepts) to rectify the lack of an explicit foundation for the practice of environmental assessment.

The need for an explicit theory of assessment based on science is clarified by considering alternative theories. Holder's (2004) cultural theory of assessment is based on the premise that it is a means for stakeholders to force the decision maker to consider their concerns and preferred alternative actions. Cashmore et al. (2008) go further and argue that the primary function of environmental assessment is to reassure stakeholders and that decision makers are often indifferent to the content of environmental assessments. Both of these theories are based on British experience with impact assessment. We do not agree with their assumptions and argue that scientific information should inform decisions rather than being a weapon for manipulating a social process. However, they show that different theoretical assumptions imply different assessment principles and practices (e.g., writing to persuade vs writing to inform).

Others use the term *theory* solely for scientific explanations of nature. If you prefer to restrict the term in that way, you might still find this discussion useful by thinking of our axioms and principles as the potentially useful judgments of 2 experienced practitioners. At minimum, we hope to make you think about the assumptions and principles underlying your own assessment practices.

We present this theory assuming that most of our readers recognize the need for environmental assessment. However, some skeptics believe that assessment is simply a means to delay appropriate action or that the actions needed are obvious without input from assessors (O'Brien 2000). Thus, we provide this brief rationale for environmental assessment.

- People depend on the environment for goods, services, and well being.
- People's actions inevitably alter the environment.
- Environmental alterations *might* be unacceptable or irreparable.
- The nature and implications of the alterations *might* be unrecognized without formal analysis because of the complexity of the environment.
- Scientifically based assessments provide the most reliable basis for determining causes and estimating environmental alterations that affect the provision of goods, services, and well being.

Therefore, decisions concerning actions that alter the environment should be based on scientific evaluations of the

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Published on the Web 7/1/2008.

consequences of those actions; hence, the need for environmental assessments. The alternative is to make ill-informed decisions that are more likely to cause harm or to benefit the few at the expense of many.

Despite the requirement in the United States and most other industrialized nations that environmental management decisions protect both human health and the environment, ecological assessments often are not influential (Appendix 1). Environmental management decisions are typically made on the basis of economic or human health assessments (Suter 2007). The lack of influence with respect to ecological endpoints probably is less attributable to inadequate science (although better science is needed) and more to a lack of assessment practices that encourage appropriate action (Appendix 1). To be successful, assessments must "have potential outcomes that lead to specific actions; must be multidisciplinary; and must have commitment from the potential beneficiaries that they are eager to hear the results and act on them" (King and Thomas 2007).

Our response is to return to 1st principles and develop a theory of the practice of environmental assessment that could result in more effective assessments. A theory is needed to predict which assessment practices will be successful and to provide a basis for understanding the roles and expectations of those involved in environmental assessment and management. When assessors understand that there is an underlying logic to successful environmental assessment, we believe that they will be better motivated. Also, by possessing a credible theory, their assessments will be well grounded, better crafted, and more persuasive.

Although this paper emphasizes ecological problems, the theory presented is applicable to health assessments or to integrated health and ecological assessments (Cirone and Duncan 2000; WHO 2001; Di Giulio and Benson 2002; Suter et al. 2003; Cormier and Suter 2008). This inclusive theory can help to bridge the gap between human health and ecological assessment practices. Hence, we use the broad terms environmental assessment, environmental epidemiology, and environmental management in this theory.

Also, although we emphasize risk assessments and the decision processes that they inform, the theory is applicable to other types of environmental assessments. These include condition assessments to find and characterize impairments, causal assessments to determine the causes of impairments, and outcome assessments to determine whether management actions have been successful (Cormier and Suter 2008).

To be clear, this is a theory of how environmental assessments should be performed on the basis of our premises, not how they are currently performed (Appendix 2).

Also, it is a theory of assessment and not of decision making or policy making. Hence, it assumes that the nonassessors involved in the process do their jobs competently and that they communicate openly and honestly with assessors (Appendix 3).

THE THEORY

Any logical system must begin with some basic underived assumptions. The definition of environmental assessment is based on 3 assumptions (i.e., the axioms of the theory) that form the basis of environmental assessment theory and from which principles of practice are derived. (The numbers are used for organization, not to convey priorities. For example, Axiom 1 is not more important than Axiom 2.) The development of the theory begins with a brief discussion of those assumptions and then derives from the 3 axioms principles that are essential for completing assessments that support sound environmental management decisions (Table 1).

Axiom 1: Assessments inform environmental management decisions

By environmental management decision, we mean choosing to take some action or no action to affect the state of the environment. Decisions to gather data or define options are not environmental management decisions, but they could be part of a larger assessment process that supports management decisions.

Axiom 2: Assessments are science based

Both the process and the knowledge used in assessments are scientific. Assessors use scientific knowledge and methods to generate useful information concerning the potential consequences of decisions. This basis in science distinguishes assessments from other input to decisions, including values, ideologies, traditions, political considerations, and legal precedents. It implies that the decision-making process depends at least partially on scientific evidence.

Axiom 3: Management decisions accommodate multiple goals and constraints

Because only 1 action or set of actions can occur at a point in time and space, each environmental problem is resolved by a single solution. Hence, there is only 1 decision (e.g., only 1 remedial plan per site and 1 permit per effluent), and all assessment activities must jointly inform that complex decision. A plan that includes multiple actions is still the result of a unitary decision and a sequence of decisions is a set of unitary decisions. Therefore, assessments must be integrated to support a decision that satisfies multiple competing goals and constraints.

From these axioms, we can derive a definition: *Environmental assessment is the process of providing scientific information to inform decisions for managing the environment.*

In addition, we can derive a set of principles that constitute our assessment theory. The derivation process is demonstrated in Appendix 4.

[1] Assessments inform environmental management decisions

If assessments are intended to inform environmental management decisions (Axiom 1), then these 6 principles and 1 subprinciple should be applied.

[1]1. Assessments are comparative—If a management decision is to be made, there must be a choice among alternatives that have different environmental consequences, and the assessment must compare those alternatives. The alternatives could be simply a proposed action and no action, but often alternative types of actions or levels or extents of the action must be compared. For example, assessors might compare the options of reducing nutrients by restricting permitted discharges versus controlling nonpoint sources. Hence, assessors should ensure that they know the options to be compared.

[1]2. Assessors must know about the decision, the decision maker(s), and the bases for the decision—There is little chance that an assessment will successfully inform an environmental management decision if the assessors do not know about the

Table 1. The axioms and principles of a theory of environmental assessment; axiom numbers are in square brackets

[1]	Assessments inform environmental management decisions		
	[1]1	Assessments are comparative	
	[1]2	Assessors must know about the decision, the decision maker(s), and the bases for the decision	
	[1]3	The form of the assessment results must be appropriate to the decision	
	[1]4	Assessment results must be understandable by the decision maker	
	[1]5	Assessments must convey the importance and urgency of the results	
	[1]6	Resources are limited	
		[1]6.1	Results should not be more complex than necessary to inform the decision
[2]	Assessments are science based		
	[2]1	Science explains the past or predicts the future	
	[2]2	Scientific quality must be assured	
	[2]3	Assessors must be unbiased	
[1&2]	Assessments inform decision processes and are science based		
	[1&2]1	Assessments must be based on causal relationships	
		[1&2]1.1	Assessments must address exposure
		[1&2]1.2	Assessments must define a functional relationship between exposure and effects
	[1&2]2	Uncertainty is always present and must be presented in a way that is useful to the decision	
	[1&2]3	Policy is input to assessments, not generated by assessors	
		[1&2]3.1	Assessors must translate goals and policies into operational terms
[3]	Management decisions must accommodate multiple goals and constraints		
	[3]1	Assessments must integrate across disciplines	
	[3]2	Assessments must integrate across sources of information	
	[3]3	Assessments must integrate across scales and levels of organization	

decision maker(s) and the type of decision to be made. For example, in the US Superfund program, decisions are made by the Remedial Project Manager, who should communicate with at least 1 member of the assessment team. All assessors on the team should know the generic goals of the National Contingency Plan for Superfund and the Remedial Project Manager's specific goals and decision criteria for the site.

[1]3. The form of the assessment results must be appropriate to the decision—The output of an assessment can take many forms, one of which will be most appropriate for a particular decision. Categorization is the most common form, usually derived from 2-part logic (e.g., acceptable vs unacceptable, remedial goals achieved vs not achieved, or impaired vs unimpaired) or 3-part logic (e.g., acceptable vs unacceptable vs something in between). The "in between" category might be "potentially acceptable, depending on cost," "acceptable but should be reduced when practical," "gather more data," or some other inconclusive result.

Estimation of conditions or outcomes is often considered the ideal form for many types of assessments. Examples include "the restoration increased fish species richness to 70% of reference" and "accidental releases are expected to cause kills of at least 100 fish with a 3-y average recurrence frequency."

Ranking of alternatives is appropriate when alternative actions are considered and the decision is to choose the best (e.g., least risk, greatest yield, most probable cause, maximum diversity). This form is the least technically demanding because it reduces to simple ordination.

Another type of result is risk-based performance metrics and restoration goals for adaptive management and restoration (NRC 2005).

The form of results should be chosen to support the method used to balance the various decision criteria (Axiom 3) and compare alternative actions (Principle [1]1). Quantitative estimates of risks are required for cost–benefit analysis and are desirable for quantitative decision analysis and some other decision support methods. However, some decision support tools accept dichotomous results. Hence, environmental assessors must determine what additional analyses, if any, will be performed using their results.

[1]4. Assessment results must be understandable by the decision maker—All assessments must be understood by the decision maker, but results of ecological assessments require more explanation than results of human health or economic assessments because they are unfamiliar to most decision makers. Decision makers, being human, are familiar with human health and with monetary costs, but they are often unfamiliar with ecological effects such as reduced ephemeropteran taxa richness or nutrient spiraling and do not understand their significance. If decision makers do not understand the results, they are likely to make the decision on grounds that are more familiar. Hence, it is not sufficient to

provide a copy of a scientifically defensible assessment. A separate management communication step must be planned and carried out (Suter 2007).

[1]5. Assessments must convey the importance and urgency of the results—In addition to being formally correct, assessment results must explicitly and compellingly answer the "So what?" question. Hence, it should express not only the nature and magnitude of effects but also the implications of the effects and their temporal and spatial dynamics. Are effects increasing or spreading? Are thresholds being approached? Might effects be irreversible (SAB 2000)?

[1]6. Resources are limited—Because assessments are performed to inform decisions that must be made within time limits by resource-limited organizations, not academic research programs that might continue indefinitely, there is never enough time, money, or people to quantify all potential effects. Therefore, assessors must plan to meet the goals of their assessments within the resource limitations and, if necessary, must make a case for more resources.

[1]6.1. Results should not be more complex than necessary to inform the decision—Extraneous data or information should not be generated. Data are extraneous if they do not provide information that could change the decision. Simple methods should be used for easy problems, such as when highly toxic concentrations are occurring. Excessively elaborate assessments mean fewer problems are addressed. Therefore, assessors should carefully consider the value of information that they generate relative to the decision criteria.

[1] Assessments are science based

If assessments are to be based on scientific knowledge and analysis (Axiom 2), then assessors must use the following 3 principles.

[2]1. Science explains the past or predicts the future—As in other scientific practices, environmental assessors must develop methods for explaining the past (environmental epidemiology) or predicting the future (environmental risk assessment and management assessment). Information is shared between the 2 practices, but the inferential logics are distinct. Hence, environmental assessors should share explanatory and predictive tools (e.g., causal models) across types of assessments.

[2]2. Scientific quality must be assured—Scientific quality refers to the correctness of the input data and technical analyses. Quality does not require the latest scientific techniques. Rather, it requires techniques that are sound, yet appropriate to the decision and to the data that are available. Hence, peer review should be applied to assessments more often, but reviewers must understand the decision context.

Scientific quality assurance does not address goals or policies. That is, science cannot judge the quality of goals set by decision makers or stakeholders or of the laws, regulations, and policies that constrain and direct assessment practices.

[2]3. Assessors must be unbiased—Although biases are inevitable in environmental management, the assessors, as scientific experts, must exert every effort to set aside their biases and resist inappropriate pressures on their science. Although subtle sources of bias are inevitable, it is possible to avoid personal financial interests and overt pressures from funders that result in biased advocacy science. Nobody expects corporate managers to equally weigh corporate interests and public interests. Even government officials have inherent biases because of the protective mandates written into most environmental laws. However, even biased decision makers need unbiased technical input. Stakeholders also have explicit biases because of their "stake" in the outcome. Assessors should consider the preferences of decision makers and stakeholders only to the extent that they are integrated into the decision maker's publicly documented goals and constraints on the assessment (Appendix 3). Peer review is an important mechanism for enforcing scientific neutrality in assessments as well as their quality.

[1&2] Assessments inform decision processes and are science based

If an assessment is to be both science based and influential in the decision process (Axioms 1 and 2), assessors must apply the following 3 principles and 3 subprinciples.

[1&2]1. Assessments must be based on causal relationships—All assessments depend on scientific knowledge of causal relationships. Once developed, these causal relationships can be used to assess whether conditions are the result of natural processes, whether an agent is sufficient to have caused an observed impairment, whether a reduction in a causal agent will have the desired effect, and whether the condition has returned to background levels. The relationships are expressed as exposure–response models for the agent of concern (e.g., atmospheric ozone) and the endpoint receptor (e.g., forest primary production). Exposure–response models are solved for estimated exposure levels to predict effects (i.e., for risk assessments) or are solved for prescribed effects to estimate the exposure level that would induce that effect (i.e., to help identify the cause of the effect or to derive criteria that are predicted will prevent the effect).

Correlations or models of associations that are not based on causal relationships can lead to ineffective decisions. For example, a correlation of nonnative fish with impaired benthic invertebrate communities does not demonstrate a causal relationship because the conditions that harm the invertebrates (e.g., elevated temperature) might permit the establishment of the nonnative fish. Thus, the causal relationship is between warmer water and fish or invertebrates and not between fish and invertebrates.

Hence, more attention should be paid to so-called stressor–response relationships as causal models of the relationship of an exposure process to a response process. Rather than defaulting to standard benchmark values or models, consider what model will yield the best estimate of the information needed.

[1&2]2. Uncertainty is always present and must be presented in a way that is useful to the decision—The purpose of data collection is to reduce uncertainty. Thus, uncertainties that could be reduced by further data collection or analysis should be distinguished from inherent variability (Suter 2007, Ch. 5). In extremely uncertain cases, adaptive management could be used to reduce uncertainty. That is, results of a tentative management action could be monitored to develop data and models that can be used in a more certain definitive assessment.

Because probabilities are often ambiguous and misinterpreted, uncertainties should, as far as possible, be presented as expected frequencies of beneficial or adverse outcomes, given the influence of variability or uncertainty on alternative decisions (Gigerenzer 2002).

[1&2]3. Policy is input to assessments, not generated by assessors—Assessors should avoid making value judgments or policy decisions. If clear goals, spatial boundaries, etc. are not provided, assessors should seek input. When necessary input is not provided by appropriate parties, assessors are still responsible for providing useful information. This can be done by providing a range of results rather than the probability of an unacceptable outcome. For example, if a regulator must set the minimum flow below a dam but has not specified an acceptable level of reduction in fish abundance, the assessor should present a relationship between abundance and flow. Other types of missing policy input might require assessors to make policy assumptions and clearly distinguish them from scientific analyses. Finally, assessors may use relevant precedents in place of current policy judgments.

[1&2]3.1. Assessors must translate goals and policies into operational terms—Goals set by laws, regulations, or individual decision makers are typically broad and imprecisely defined (e.g., protect biological integrity). To perform a scientific analysis, these goals must be translated into assessment endpoints, which are entities and associated attributes (e.g., fecundity of bald eagles) (USEPA 1998). Assessors must assure that their definitions encompass the decision maker's definitions of the goals. Similarly, policies that constrain assessments often must be defined operationally. For example, when writing an effluent permit to protect an aquatic ecosystem, should the ecosystem be bounded at the pipe, after a zone of initial dilution, in the 1st fully mixed reach, or by some other limit? Assessors should make these translations and interpretations with care and should obtain approval whenever possible. They could become precedents or even common practice without ever being properly vetted.

[3] Management decisions must accommodate multiple goals and constraints

Because more than 1 resolution is possible and the choice will affect multiple attributes of the environment and society (Axiom 3), the assessor must incorporate the following 3 principles into the assessment process.

[3]1. Assessments must integrate across disciplines—Integration across disciplines is necessary because it is not possible to make 1 decision that protects the environment, another that optimizes wealth, another that is minimally disruptive of social structures, etc. The management decision affects all issues simultaneously. It would be rare that all were optimized by the same action. Therefore, the decision must balance many goals through a synthesis of ecological, human health, economic, engineering, and other assessments. Too often, assessors present the decision maker with disciplinary apples and oranges, so the decision maker must perform his own subjective synthesis or simply choose the answer that he likes best from among the disciplines. Rather, the various assessors should determine the type and degree of integration preferred by the decision maker and should collaborate to provide the integrated results. The integration might be performed by simply estimating ecological, health, and economic effects for a common scenario and common spatial and temporal scales and presenting the results in a table for comparison of the alternative actions. At the other extreme, a quantitative decision analysis can be performed that reduces all outcomes to monetary or utility units (Linkov et al. 2006; Seip and Wenstop 2006).

[3]2. Assessments must integrate across sources of information—An assessment, such as an ecological or human health risk assessment, must integrate information from all prior or concurrent assessments (e.g., epidemiological investigations) with all information generated for that assessment. That implies a need to perform an analysis of the weight of evidence.

[3]3. Assessments must integrate across scales and levels of organization—Scientific processes operate at different scales and on different levels of organization; therefore, assessments must as well. For example, the decline in a brook trout fishery might be due to local habitat change as well as regional acid deposition. Also, a decision that is good for an ecosystem should not, without good reasons, be harmful to an important population such as a game fish and should attempt to benefit regional as well as local ecosystem properties. Hence, assessments should consider and report in relevant terms the effects at relevant scales and levels of organization.

IMPLICATIONS OF THE THEORY

When the principles of assessment theory are not applied, the results are likely to be a disappointing waste of good intentions. For example, monitoring programs are sometimes implemented that are intended to describe conditions at a site or region. If the information is not interpreted and related to decision making, it is of limited use. A particular example is the census of fish in the locks along the Ohio River performed since 1957 (ORSANCO 1978; Pearson and Pearson 1989). In 1992, this legacy data set was analyzed for trends that suggested that there were fewer pollution-tolerant fish in 1992 than in 1957 (ORSANCO 1992). The analyses showed that the fish assemblages had changed, but the information was not useful for action-directed decision making. There were no criteria for determining the significance of changes, and no attempt to ascertain whether changes were due to natural causes, operations of the locks, improved waste water treatment, or other causes. This is descriptive statistics, not an environmental assessment. Reports from the biological surveys of the locks did not function as assessments, because they did not inform management actions (Axiom 1) and did not establish any causal relationships that could lead to action (Principle [1&2]1).

Given sufficient impetus, such monitoring programs can become assessment programs. For example, studies of the death of fish stranded on the Falls of the Ohio, which were dewatered by operation of the McAlpine lock and dam, qualify as assessments. They assessed the damage, determined the cause, and compared the risks of alternative actions, leading to new practices that reduced fish strandings (Pearson and Froedg 1989).

When assessments do not integrate different types of scientific information and goals (Axiom 3) and do not compare options (Principle [1]3), there is an assessment, but the resulting decisions can be costly and might not result in desired outcomes. This problem could occur when planning the remediation of a contaminated site. The assessors typically focus only on the contaminants, thus failing to recognize the effects of remediation and the importance of habitat structure to meeting environmental goals (Peterson et al. 2003; Cleveland 2007; Cormier and Ferster 2007).

Similarly, practices that control 1 problem but ignore others can result in unintended consequences (Axiom 3, Principle [1]3). For example, flood abatement and control programs often do not adequately take into account alter-

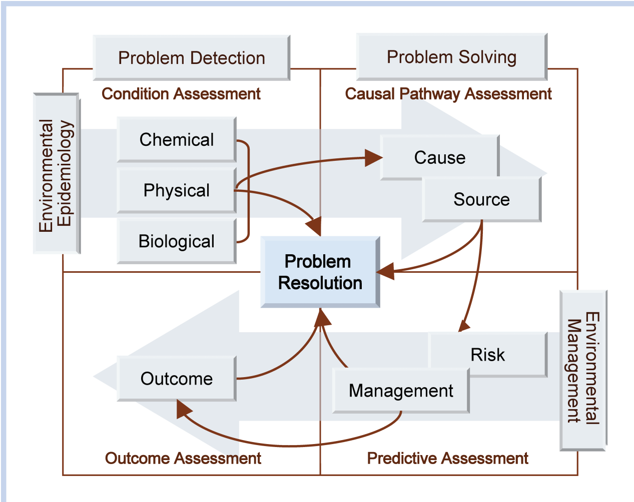

Figure 1. An integrated environmental assessment framework depicted as a matrix of assessments that includes problem detection (**left column**) and problem solving (**right column**). The rows of the matrix are based on the direction of the inference: Eco-epidemiology studies are assessed from effect to cause (**top row**), whereas environmental management is assessed from cause to effect (**bottom row**). All assessment can potentially lead to a resolution of an environmental problem (**central rectangle**). (Adapted from Cormier and Suter 2008.)

ations to other environmental benefits, such as water and sediment supply, habitat for wildlife, aesthetics, or cycling of nutrients. Disruption of sediment distribution in the Mississippi drainage has led to land subsidence (Brody et al. 1993; Morton et al. 2005) and loss of wetlands, contributing to the destructive effects in Louisiana of Hurricane Katrina in 2005.

THEORY AND FRAMEWORKS

Understanding the theory of a practice is not enough. Satisfactory environmental results are more likely when the principles are applied in a coordinated and consistent fashion within a sequence of assessments that include accountability. Existing frameworks such as the risk assessment frameworks by the US Environmental Protection Agency (USEPA 1992), National Research Council (NRC 1983), and Presidential Congressional Commission (1997) incorporate only a part of the assessment and management process or treat all types of assessment as risk assessments. Others are specific to particular regulatory processes (US Department of the Interior 1987; Sprenger and Charters 1997). None of them are focused on making decisions that result in resolution of environmental problems.

A new environmental assessment framework is consistent with the theory presented here (Cormier and Suter 2008). It focuses on successfully ending the assessment process by resolving the problem (Figure 1). It recognizes that risk assessment does not meet all assessment needs and that separate assessments are needed to identify existing impairments, to determine the causes of impairment, to predict the effects of management actions including no action (true risk assessment), to select a management action, and to determine whether the action was successful.

CONCLUSIONS

We have developed this theory of environmental assessment for practical reasons. We believe that a theory-based practice is more likely to be coherent and compelling than an ad hoc practice or a standard practice that lacks explicit assumptions and logic (Cartwright 2003). Like other theories of practice, it is derived from personal experience, knowledge of the experience of others, and logic. Hence, it cannot be disproved but it can be supported or weakened by the experience of those who attempt to put it into practice. We hope you will find it useful, but we are confident that, if you have read this far, you will be inclined to examine your own experience and expand or modify the principles to meet your own needs and improve the practice of environmental assessment. If environmental assessments are often effective only as props for sociopolitical processes (Holder 2004; Cashmore et al. 2008), a cure for that is to make the science so relevant and compelling that it cannot be ignored.

Acknowledgment—We appreciate the constructive criticisms of Jay Messer, Michael Kravitz, Larry Barnthouse, Rick Linthurst, Michael Troyer, Mark Burgman, and anonymous reviewers. The paper was written on our own time and was not supported financially or in-kind by any organization or agency.

Disclaimer—Although this paper has been subject to USEPA review and clearance, the ideas in this paper are our own and do not represent the policies or recommendations of the USEPA.

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APPENDIX 1. Example of lack of influence of environmental assessment

As an example of lack of influence, consider the Coeur d'Alene River Basin, Idaho, USA, which is a Superfund site because of widely distributed wastes from lead mining and smelting. It was the subject of an ecological risk assessment based on high-quality data that revealed mass mortalities of waterfowl, extirpation of trout populations, and other severe effects. However, a review (NRC 2005) concluded, "Despite the large number of ecological studies performed in the basin and the complexity of the analyses provided in the Ecological Risk Assessment (ERA) report, the results of the ERA had only a minimal apparent influence on the ROD [Record of Decision]" (p 320). A pertinent recommendation was, "ERAs . . . should be designed to support remedy selection and not simply to document the presence or absence of risks" (p 321).

APPENDIX 2. Rational decision process?

As scientists, we take a rationalistic approach to the process of environmental decision making. However, we recognize that decisions are not always made in the manner described. Decisions that are, by statute or regulation, intended to be based on science can be driven by politics or sidetracked into the courts. Yet, we believe that most environmental management decisions are resolved in a rational manner that, although imperfect, balances values and interests within legal constraints. By improving the relevance of the scientific input and increasing the transparency of the process, we hope to increase rationality of environmental management processes.

APPENDIX 3. Roles and responsibilities of decision makers

This discussion of assessment theory is intended for environmental assessors and therefore focuses on their responsibilities. However, it must also be recognized that the success of assessors depends on the performance of decision makers. The following are some of the most important responsibilities of the decision maker with respect to environmental assessment. They imply a greater willingness of risk managers to communicate with assessors and stakeholders than is common (Dale et al. 2008).

Define goals—The goals of the environmental management action must be defined clearly.

Define constraints—The time limits and resource constraints must be known in advance, and changes in the timeline must be communicated promptly.

Engage stakeholders—When individuals or organizations have an important stake in a decision, those stakeholders must be involved early in the process to share information with the assessors and to ensure that their concerns can be incorporated into the definition of assessment endpoints and models.

Remain engaged throughout the process—Often interim findings from ecological, health, or engineering assessments will reveal issues that should cause adjustments in goals or constraints. If decision makers do not remain sufficiently engaged to make those adjustments, the assessments will not effectively support the decision-making process.

Make appropriate decisions—Decision makers should make the necessary effort to understand the scientific input from assessors and assimilate it with other considerations to select an alternative that will achieve the stated goals.

APPENDIX 4. An example of the derivation of principles

We hope that the relationships of the principles to the axioms are apparent from their descriptions, but an example might help clarify the logic of the derivation process. The following principle is derived from both Axioms 1 (assessments inform decisions) and 2 (assessments are science based); the combination is designated by [1&2]. It is the 1st principle derived from those axioms; hence, it is designated [1&2]1.

[1&2]1. Assessments must be based on causal relationships

It follows from Axiom 1 because you cannot design an effective management action without defining a causal relationship that will be manipulated.

It follows from Axiom 2 because science provides more reliable causal relationships than alternative "ways of knowing."

Principle [1&2]1 implies 2 subprinciples. The numerals after the brackets designate the principle and the subprinciple.

[1&2]1.1. Assessments must address exposure—This follows because effects are not caused without exposure to the causal agent.

[1&2]1.2. Assessments must define a functional relationship between exposure and effects—This follows because the causal relationship must be defined in a way that allows prediction (environmental management assessments) or explanation (epidemiology) (Figure 1).

Hence, in 2 steps, we can go from fundamental principles to the 2 components of the analysis phase of risk assessment (USEPA 1992) and to the most important types of evidence in the Stressor Identification methodology for causal assessment (USEPA 2000). In particular, the causal criteria C*o-occurrence* and *complete exposure pathway* are instances of the exposure principle ([1&2]1.1), and the various exposure–response criteria are instances of the functional relationship principle ([1&2]1.2).