Peer Reviewed: A Comparative Analysis of Environmental Risk Assessment/Risk Management Frameworks

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A Comparative Analysis of Environmental Risk Assessment/Risk Management Frameworks

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Risk assessment/risk management frameworks have been developed to address environmental impacts. Seven representative frameworks were analyzed for common themes, differences in approach, and conceptual innovations. Frameworks continue to undergo dramatic changes in form and emphasis. All maintain an important role for science. Trends toward greater stakeholder involvement, decreased emphasis on quantitative characterization of risk and uncertainty, and development of iterative decision-based analysis cycles in frameworks suggest a move toward embedding risk assessment within risk management and placing greater emphasis on the latter. Successive frameworks offer analytical innovations which, in sum, point to greater social participation in the conduct, interpretation, and use of risk assessment/risk management analyses. This is because technical analysis and command-and-control regulation have either failed to deal satisfactorily with environmental problems or, in suggesting solutions, have created conflict with other valued social objectives. No consensus on a comprehensive framework has emerged.

Risk assessment/risk management is one of the most important environmental policy developments of the past decade. Modern societies recognize that their activities both depend upon and have consequences for the environment. Effects of human activity have an impact on sociopolitical institutions (*1*) and environmentally dependent systems, such as the economy, human health, and natural ecosystems at different spatial and temporal scales. The resulting range of issues that needs to be considered when assessing potential impacts (*2*) has driven the development of environmental assessment frameworks in many countries. Although not examined in this report, other frameworks besides those analyzed exist, including those that focus on human health, engineering, and social risks (*3–5*). Here the emphasis is on frameworks dealing specifically with environmental aspects of risk assessment and decision making.

The Netherlands

Released in 1989 as part of the national environmental policy plan, the Netherlands Ministry of Housing, Physical Planning and Environment (MHPPE) framework for risk management argues for the adoption of environmental risk analysis techniques to develop effect-oriented environmental policies (*6*). The framework consists of five key steps: identification of dangers to humans and the environment; estimation of the magnitude and probability of occurrence for identified dangers; assessment of the acceptability of identified risks; prevention, where possible, of risks; and, failing that, maintenance of acceptable levels of risk. An important feature of the framework is the definition of risk limits for particular combinations of receptor objects, effects, and stressing agents. Other important objectives include the provision of guidelines for assessing risks associated with widely differing agents, establishment of environmental priorities, assessment of the environmental return from exercise of policy options, and provisions for ensuring the comparability of protection levels from differing pollution sources. The policy aims at the eventual design of an analytical decision-making framework within which rational social decisions on risk can be made, while recognizing that risk assessment is only one of the methods likely to be used in environmental policy development.

The framework explicitly states numerical values for maximum permissible and negligible risk levels associated with either mortality or threshold response effects at the individual, group, and collective (ecosystem) levels (for example, the concentration

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of a substance that removes no more than 5% of the species in an ecosystem). The policy acknowledges that some guidelines, such as the requirement to protect 95% of the species in an ecosystem, are arbitrary. Moreover, despite criteria for judging the acceptability of extreme risks, the policy does not develop a definite framework for implementing risk limitation schemes. Although assessment-related techniques are considered useful for establishing general environmental quality and priority objectives, they are not considered useful for specific policy design or management action. Details of both are left to unspecified deliberative processes that take social considerations into account. Instead, framework discussion focuses on obvious options, including reduction in the extent or likelihood of emissions, increasing the separation between receptor and source, and use of remedial actions.

The U.S. Environmental Protection Agency

The development of ecological risk assessment guidelines (*7*) was spurred by increasing interest in ecological issues and a Science Advisory Board (*8*) recommendation for increased emphasis on risk-based decision making. The framework draws heavily on existing human health paradigms (*9*) and describes the basic elements needed for evaluating scientific information about potential adverse effects of physical and chemical stressors on the environment. It consists of three major phases: problem formulation, analysis, and risk characterization. Initially intended for use by EPA and contractors, the framework is now widely used.

Critical to this success was the introduction of problem formulation. The notion that both in terms of social and scientific aspects, complex environmental issues can be focused for objective analysis within a well-defined technical process, promoted the subsequent popularity of the framework. Best described as a scoping or planning phase, problem formulation aims at establishing the goals, breadth, and focus of an assessment. Though recognition of stakeholder input in the process is implicit, emphasis is placed on the scientific definition of the problem under study.

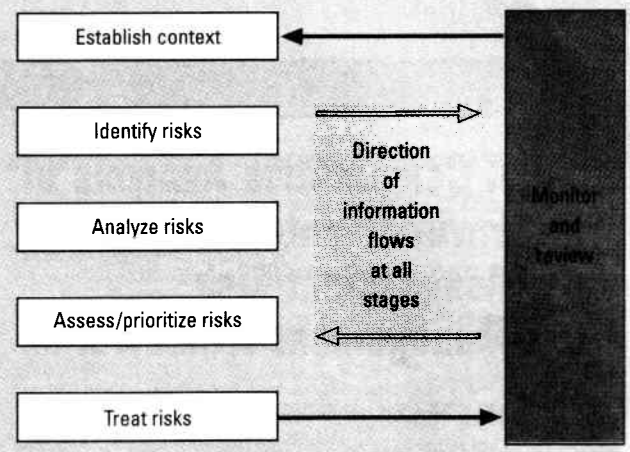
The analysis phase, which is the scientific component of an assessment, is divided into two equally important activities: exposure and effects characterization. It is designed to ensure that the best available information is used to develop both an exposure profile of the extent and duration of stressor actions on biota and an effects profile summarizing the effects of stressors on chosen assessment endpoints. Risk characterization forms the final assessment step in which exposure and effects data are integrated to qualitatively or quantitatively describe risk. This step includes a description of the risks in terms of selected assessment endpoints, a determination of their ecological significance, an expression of confidence in assessment results, and communication with risk managers.

The framework is intended primarily to address assessment practice issues, but it also recognizes the importance of indirectly related activities. Discussions between risk assessors and managers and the completion of verification and monitoring studies are seen as integral, but separate, parts of the overall assessment process. In practice, these latter activities have been ignored. Menzie-Cura, in a review of the framework (*10*), noted that discussions on regulatory improvements focused on the need to clarify goals during problem formulation and to improve risk communication. Proposed changes to the framework (*11*), if adopted, will address many of these concerns. For example, the explicit focus on the iterative nature of the assessment process accommodates concerns for inclusion of stakeholder input, as does discussion of costs and benefits. Increased emphasis on problem formulation, however, only underscores the need to develop goals and measures of success before beginning the analysis phase of an assessment.

FIGURE 1

The Australia/New Zealand framework

The standard views risk management as a logical, iterative process, consisting of well-defined steps to support better decision making. The flow of information between identified steps and the monitoring and review requirement can initiate iterative feedback at any stage in the analysis.



Australia/New Zealand

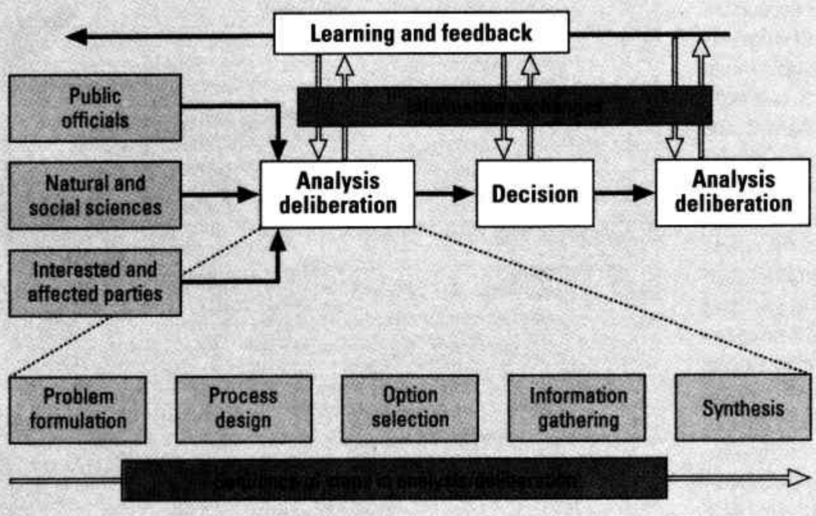
The Australia/New Zealand framework (ANZ) provides a generic framework (Figure 1) for all aspects of risk management (*12*), environmental or otherwise. It highlights the need to define stakeholder groups and interests when scoping the nature, extent, and goals of the assessment/management exercise and requires that criteria be developed against which the significance of risk can be judged. These criteria allow risks to be quickly prioritized, thereby avoiding controversies that have plagued many environmental assessment/management undertakings. As a result of the need for criteria development, the approach was among the first to place specific emphasis on inclusion of stakeholder needs.

The risk identification phase of the framework discusses the use of relevant tools and techniques to examine what as well as how and why a risk scenario can happen. The analysis phase determines the likelihood and consequences of an event within the con-

FIGURE 2

U.S. National Research Council risk characterization

Analysis uses rigorous, replicable methods to arrive at factual answers intended to inform deliberation. Deliberation is any activity aimed at communication and collective consideration of risk that serves to frame analysis. Important to the analytic–deliberative process are inputs from multiple stakeholder groups and deliberative exchanges at each step that promote iterative feedbacks for continuous improvement in risk characterization decision making.



text of existing risk controls. Although the demand is for judgments based on full information, the framework recognizes the inevitability of decisions based on incomplete information. Accordingly, qualitative and semiquantitative analyses are allowed, and sensitivity analysis is stressed.

The core of the framework analysis is the comparison of estimated levels of risk to previously established risk criteria. The assessment output is a prioritized list of risks requiring further management action. The list is determined within a social context. Thus, issues related to the tolerance for and costs, benefits, and perceptions of risk must be addressed. The risk treatment phase then focuses on selection of a risk management strategy (avoidance, acceptance, likelihood and consequence, reduction, and transference). To evaluate options, risk reduction and benefits are compared with achievement costs; however, it is stressed that this analysis should not dominate the evaluation of treatment options.

The monitoring and review obligations and information exchanges occurring between assessment/management steps are designed to initiate iterative returns to previous steps at any stage in the process. This process ensures that management actions remain relevant and helps identify factors that may improve future management practice.

U.K. Department of the Environment

The United Kingdom Department of the Environment (U.K. DOE) guide to risk assessment and management is based on four principles (*13*). Most important is the requirement that all environmental risk assessment and management activity contribute to the nation's sustainable development strategy. Critical in this context is the use of the precautionary principle that where significant risks of damage to the environment exist, action must be taken to limit potentially damaging activities, even when scientific knowledge of possible effects is inconclusive. The principle is based on the view that prevention often costs less than remediation. The selection of a course of action is tempered by requirements to base decisions on the best scientific information and consideration of costs and benefits.

In place of problem formulation, a detailed description of the action likely to affect the environment, such as a chemical release or project construction, must be developed. Descriptions are completed before the structured gathering of information about risks and the completion of risk estimation and evaluation. Estimation focuses on intention consequences and, as a result of information deficiencies, will inevitably involve judgment. Evaluation determines the significance of an estimated risk, and because of risk perception, will be subjective. The outcome of these activities supports management, which uses risk data to make and implement decisions about risks based on the balance between costs and benefits for a range of options. Once a management decision has been made, monitoring is performed to generate the information for postdecision evaluation and the improvement of option selection.

Although risk management is described as occurring after the completion of risk assessment, in practice it is an integral part of the assessment process, because a decision to alter risk management strategies restarts the assessment process. Management is part of an iterative cycle that links assessment to monitoring. Decisions are not based on the original stated intention or costs and risks of fulfilling it. Instead, they are modified by the iterative process during all aspects of the analysis, including refinement of the statement of intention and consideration of nonmonetary environmental costs and assessed risks. Despite improvements that can be realized through iteration, the U.K. DOE guide recognizes that a structured approach to assessment will never provide more than a statement of necessary criteria for effective decision making. Other social information and controls are required to sufficiently develop a complete decision-making framework.

U.S. National Research Council

The U.S. National Research Council (NRC) report on risk (*14*) was developed in response to concerns that although considerable resources were devoted to understanding risk, uncertainties about risk information continued, and existing methods failed to meet expectations about improving risk-related decision making. The report addresses opportunities for improving risk characterization that can resolve risk controversies and better inform decision makers. A key conclusion is that fundamental changes are required in the use of information by risk managers, individual decision makers, and the public.

Risk characterization is seen as a decision-driven activity, directed toward informing choices and solving problems. For interested and affected parties, this involves developing a broad understanding of the relevant losses, harms, or consequences of risk management options. These insights can only be obtained from an extensive analytic–deliberative process (Figure 2).

Early views of risk characterization as the final step, one that brings together exposure and dose response data (*9*) to summarize the analysis process for subsequent decision making, were reinforced in 1992 when EPA adopted a similar definition (*7*). The 1996 NRC report argues that such a definition is insufficient because it suggests risk characterization is adequate if it accurately represents scientific information. Science may describe the effects of different actions, but it cannot tell how effects should be weighted in social decisions. Because many stakeholders with differing goals and objectives use risk characterizations, these need to consider a wide variety of pertinent outcomes or consequences. This makes problem formulation of paramount importance and suggests that the risk analysis process is further framed by deliberation about potential risks relevant to social, ethical, and other values, which are at least as important as traditional concerns about health, safety, and the environment.

The emphasis on deliberative processes, stakeholder involvement, and broadening the scope of issues included during the problem formulation phase recognizes that a rigid distinction between assessment and management is not desirable. Because the latter insulates scientific activity from political pressure, it fails to recognize that scientific risk assessment activities are not sufficient by themselves to provide the needed public understanding of risk. Deliberation frames analysis but cannot precede it. Therefore, assessment is linked to management in a complex iterative cycle.

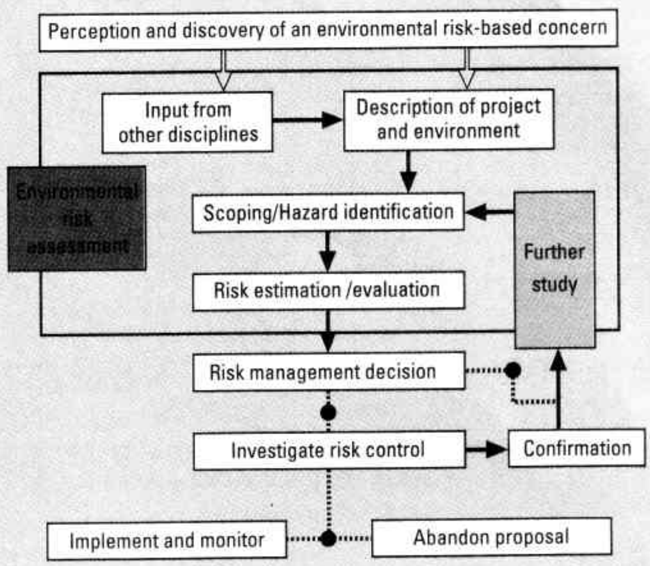
Canadian Standards Association

Risk assessment was initially embedded within a risk management framework (*15*) by the Canadian Standards Association (CSA). The CSA has since developed a separate assessment (*16*) and a draft management standard that maintain the hierarchical relationship between the two. Although technically similar to the EPA framework (*7*), the CSA assessment standard includes a more explicit discussion of the requirement for stakeholder involvement (*16*). It further recommends consideration of multiple stressor effects, inclusion of social values in the identification of valued ecosystem components, and recognition that risk acceptability should be determined in conjunction with consideration of alternative courses of action. These improvements have less to do with deficiencies in the EPA framework than

FIGURE 3

The Canadian Standards Association framework

Assessment is triggered by social concerns and influenced by a feedback loop dependent on risk management decision making and the feasibility of implementing risk control options. The conceptual core of the U.S. EPA framework remains in the Canadian standard, including problem identification based on limited stakeholder input, exposure-based and effects-based risk estimation, risk evaluation (characterization), and management.



Source: Redrawn from Reference 16.

with the years of operational experience gained with risk assessment.

The broadening of the discussion on stakeholder involvement focuses specifically on endpoint selection and requires both social and scientific input. Ecological screening (scientific input) is used within the framework to select measurable endpoints with predictive significance. Social screening (social input) is used to identify the correspondence between technical and societal views on valued ecosystem components. Although the selection process is iterative and discursive in nature, guidance is not provided for cases in which there is no consensus between the outcome of ecological and social screenings.

The embedding of assessment within risk management forces explicit discussion of decision making, including decisions to accept risk and implement monitoring strategies, select between control strategies, and abandon a risk-related activity (Figure 3). Because of its decision-making focus, the CSA standard includes decision points that allow choice between the actions of obtaining more information and making decisions based on available information. The CSA subscribes to the notion of tiered assessments, noting that tiering can appropriately identify when assessments need to be broadened to improve decision making.

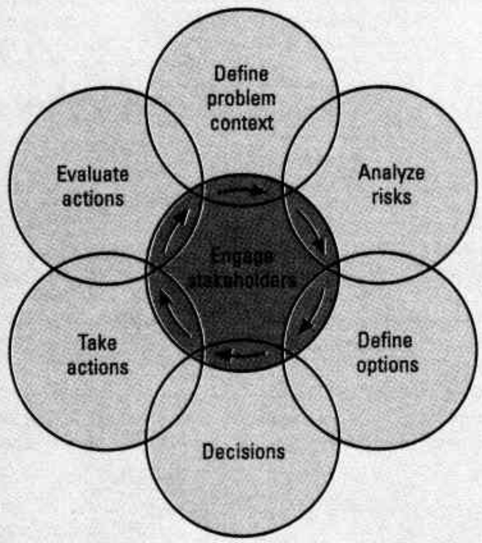
U.S. Risk Commission

The Risk Commission report (*17*) provides an important commentary on how risk assessment can be improved by the inclusion of explicit discussions on

FIGURE 4

U.S. Presidential/Congressional Risk Commission paradigm

Risk management is implemented in an interlinked six-step process that has stakeholder involvement as its focus. The steps include definition of the risk assessment/risk management problem within its social and ecological context, analysis of risks, definition of risk management options, decision making, option implementation, and evaluation.



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how and when stakeholder involvement in the assessment process should be sought. In addition, risk assessment per se is criticized for not paying enough attention to additional factors that influence risk management decisions, such as costs and legal constraints. These criticisms are reflected in the commission's definition of risk management as a process for identifying, evaluating, selecting, and implementing actions to reduce risk to human health and ecosystems and whose ". . . goal is scientifically sound, cost-effective, integrated actions that reduce or prevent risks while taking into account social, cultural, ethical, political, and legal considerations."

In developing the framework (Figure 4), the Commission relied on the following three principles. Broader analytical contexts are required for assessment of stressor effects and determination of their significance. Stakeholder participation in all phases of the assessment/management process should increase regulatory efficiency and effectiveness. Iterative processes are better suited to determine when modifications to a course of action are required and might improve the outcome of management activities.

Noting that scientific analysis underpins risk management, the Commission stresses that the nature, extent, and focus of assessment activities must be guided by social concerns as expressed in management goals. The Commission focuses on management goal selection and the engagement of stakeholders. The emphasis on goal identification makes it clear that risk assessment is subsidiary to policy-dominated risk management. Discussion of the analysis phase notes numerous deficiencies in the current practice of risk assessment, including inadequate data for risk assessments, the limitations of tests on laboratory organisms, technical uncertainties involved in extrapolation from laboratory tests, and failure to account for multiple and cumulative exposures.

The examination of management options for addressing risks involves option identification and analysis. Management options include prevention, limitation, use of economic incentives, education, and compliance enforcement. From among available options, selection is driven by analysis of expected benefits and costs (monetary and nonmonetary), the equitable distribution of benefits and costs, the feasibility of considered options, and the effect of each option on other risks. However, economic analysis must not be the overriding determinant of risk management decisions.

The Risk Commission notes that a variety of groups, agencies, or people may make a risk management decision and that selection of the appropriate authority will vary case by case. Although some general decision-making principles are listed, no usable criteria for making decisions are provided. The report stresses that decisions must not be postponed simply to gather further information and suggests that value-of-information techniques may be used to resolve decision-making impasses. In addition, the report emphasizes the need to evaluate management action. Evaluation uses feedback loops that facilitate updates and improvement of management action, thereby underpinning the important dynamic nature of processes required for risk decision making.

Differences and commonalities

The practice and paradigms of risk assessment and management have developed to become important instruments of environmental policy. Frameworks were initially designed to prevent or reduce risk (*6*) and supply information to the risk management process (*7*). More recent frameworks improve aspects of the risk management process, including risk characterization (*14*), decision making (*12*, *16*), or management per se (*17*). Modifications to earlier attempts to guide the complexities of environmental decision making should not be interpreted to mean that earlier frameworks were a failure. Attempts have only been aimed at improving limited aspects of the risk assessment/management process, a testament to the success and utility of the early frameworks.

The most striking agreement among the frameworks examined centers on the role assigned to science (Table 1). All frameworks stress the fundamental importance of appropriately conducted and reviewed scientific practice. Not all agree on the primacy or separation of science from policy. Some, such as the MHPPE (*6*) and EPA (*7*) frameworks, only address the role of science in risk estimation, where it is used in isolation to inform management. Others, such as the Risk Commission (*17*) framework, place science in the context of social decision making, where it is one of many inputs used to drive risk-based decisions. Some frameworks view science as not wholly objective because it is capable of influ-

TABLE 1

Comparison of commonalities and differences among frameworks

In spite of differing objectives, ages, nations of origin, and sponsoring agencies, a number of critical themes are common to all frameworks. Tabular entries provide summary descriptions of the stated development purpose and key conceptual innovation of each framework. Agreements among frameworks suggest likely future changes in risk assessment and risk management processes. Differences reveal temporal changes in attitude toward the measurement and management of risk.

Issue	U.S. Risk Commission 1997	Canadian Standards Association 1996	National Research Council 1996	U.K. Department of the Environment 1995	Australia/ New Zealand 1995	U.S. EPA 1992	The Netherlands 1989
Framework's prime objective	Risk management	Environmental decision making	Risk characterization	Risk management	Risk management decision making	Risk analysis	Risk reduction
Assessment versus management	Explicitly management-oriented	Assessment embedded in management	Explicitly management-oriented	Assessment embedded in management	Explicitly management-oriented	Explicitly assessment-oriented	Implicitly management-oriented
Decision making	Decision-oriented, comments on principles and techniques	Decision-oriented, identifies specific decision points	Decision-oriented, decision making used for problem solving	Implicitly decision-oriented, requires balance in decision making	Decision-oriented, stresses a priori criteria for decision making	Not decision-oriented, decisions deferred to risk management	Decision-oriented, includes specific regulatory objectives
Stakeholder input	Strong emphasis on input use	Weak emphasis on input use	Strong emphasis on input use	Implicit emphasis on input use	Strong emphasis on input use	Implicit emphasis on input use	Implicit emphasis on input use
Role of science	Necessary for risk management decision making	Necessary for risk estimation	Necessary for assessment, but insufficient alone	Necessary for risk management decision making	Necessary for risk estimation	Necessary for risk estimation	Necessary for risk estimation
Socioeconomic valuation	Viewed as useful in decision making	Excluded in decision making	Used to broaden risk understanding	Used in decision making due to resource limits	Notes need for cost–benefit analysis	Not included	Costs used to select among regulatory options
Uncertainty analysis	Prefers qualitative to quantitative methods	Requires quantitative methods	Prefers both qualitative and quantitative methods	Stresses qualitative and quantitative methods	Requires qualitative and quantitative methods	Requires quantitative methods	Requires quantitative methods
Risk characterization	Should be both qualitative and quantitative	Emphasizes quantitative approaches	Should be both qualitative and quantitative	Will be partially qualitative due to information gaps	Can be either qualitative and/or quantitative	Emphasizes quantitative approaches	Emphasizes quantitative approaches
Risk prioritization	Important in risk management	Uses qualitative *de minimus* and *de maximus* ranking	Implicit in risk management	Necessary but not always precise	Core management activity completed using criteria	A derivative property of repeated assessment	Completed by comparing risks to standards
Linear versus iterative	Iterative at all stages	Iterative between assessment and management	Iterative at all stages	Iterative at all stages	Iterative at all stages	Iterative between assessment and management	Linear with implicit feedbacks
Key innovation	Includes social, ethical, and economic values in risk analysis	Recognizes the primacy of management over assessment	Recognizes the analytic–deliberative nature of risk-based decision making	Explicit use of the precautionary principle in the face of uncertainty	Emphasizes the comparison of risk to a priori decision criteria	Formalizes the problem identification phase	Specifically states numerical management standards

encing and being influenced by the social milieu in which it operates (*13, 14, 17*).

The shift in emphasis on the role of science is at the root of differences in views about activities that comprise the problem formulation/context phase of frameworks and the requirement for stakeholder input. Frameworks that favor isolating science from management tend to place little emphasis on stakeholder consultations or the inclusion of anything other than technical information in assessment scoping. In such frameworks, societal views are recognized but are incorporated into the assessment/management process separately from science. This is most true of the MHPPE (*6*) and EPA (*7*) frameworks. Others, such as the U.K. DOE (*13*) framework, demand broader definitional contexts and greater roles for stakeholder input (*14, 17*). The temporal trend has been toward the development of more inclusive processes, less dominated by technocratic practice, which ask those affected by risk to participate in the selection of risk management options capable of meeting multiple social goals. Proposed changes to the EPA framework are consistent with this trend (*11*).

Problems with data inadequacies and use are raising concerns about ability to accurately estimate risk.

The dichotomy in views on the primacy of science and the importance of stakeholder inputs is reflected in the relative emphasis placed by different frameworks on risk management in preference to risk assessment. Earlier frameworks are assessment-oriented and take the view that management cannot proceed without appropriate information. Later frameworks (*13*) view technical information as neither necessary nor sufficient for designing sensible public policy. Environmental risk has evolved to become less an issue focused on determining quantitative estimates and more an issue focused on balancing multiple social interests to achieve consensus. Part of that consensus involves risk minimization. It also involves the maintenance of economic opportunity and the achievement of stated risk reductions at reasonable cost (*13, 17*).

The need for balancing multiple objectives underpins the prominence given to decision making in the newer frameworks. The ANZ (*12*) framework is the most explicit, demanding the development of a priori decision criteria before the commencement of assessment activities. At the other end of the spectrum, the EPA (*7*) framework defers decision making to an ill-defined risk management process. The proposed EPA guideline revisions (*11*) suggest little change. An outlier in the trend toward greater description of decision-making activities is the Netherlands policy (*6*). The MHPPE framework anticipated later developments with the use of trigger values that determine whether a measured risk is to be treated (exceeds maximum permissible risk value), ignored (is less than negligible risk value), or treated on a case-by-case basis (all others). Although later North American frameworks (*14, 16, 17*) are decision-oriented, they do not detail the mechanics of decision making as clearly as either the ANZ (*12*) or MHPPE (*6*) frameworks.

Temporal trends are apparent in the treatment of risk prioritization. The MHPPE (*6*) framework discusses setting priorities by ranking assessed risks against provided standards. ANZ (*12*) stresses risk prioritization as the core management activity, achievable only by using the problem formulation phase to develop socially acceptable a priori criteria. The U.K. DOE (*13*) framework notes that information gaps and issues related to risk perception may preclude precise numerical ranking of risks and suggests the use of a qualitative ranking scheme. Mechanisms for risk prioritization are not discussed in later North American frameworks. They are left as an issue to be determined as part of deliberations with stakeholders. This contrasts sharply with the EPA (*7*) paradigm and a proposed update (*11*) that makes no direct comment on risk prioritization. Although it is clearly a motivating factor in the development of the framework, risk prioritization is treated largely as a derivative property of repeated assessment.

Changes in attitudes toward the use of socioeconomic information, risk characterization, and uncertainty analysis are also evident. Because of limited resources for risk management and improved abilities to identify and assess risk, it has become increasingly necessary to ensure that risk reductions are achieved at reasonable cost (*13*). The trend has favored an increased emphasis on the inclusion of cost–benefit analysis in decision making. While recognizing the role of economic analysis, frameworks that include it (*12, 13, 17*) are careful to note that it should not be the overriding determinant in decision making.

In risk characterization the trend is toward decreasing emphasis on the quantification of risk. EPA (*7*) allows qualitative characterizations but prefers quantitative expression of risk. This is also true of the MHPPE (*6*) approach, which characterizes risk by comparing estimates to stated thresholds. In contrast, the ANZ (*12*) framework, where necessary, encourages the use of qualitative characterizations. The U.K. DOE (*13*) framework includes specific categories for qualitative characterization, and the NRC (*14*) framework emphasizes the need to summarize nonquantitative social, ethical, and other values. The Risk Commission (*17*) framework statement argues further that quantitative characterizations are insufficient. Qualitative information must be included to make the differences in exposure conditions as well as the nature and strength of evidence supporting a given view of risk understandable to the public. At odds with this trend, the CSA (*16*) framework restates the EPA (*7*) position on the preference for quantitative estimates.

The trend in preferences for qualitative characterizations of risk reflect growing concerns about abilities to accurately estimate risk given data inadequacies and difficulties with extrapolation. All frameworks agree that the uncertainty associated with risk estimates must be stated. At issue is whether such statements should be primarily qualitative or quantitative in nature. At one end of the spectrum are the MHPPE (*6*) and CSA (*16*) frameworks that look at uncertainty analysis as a purely technical exercise. Although practical applications of the EPA (*7*) framework have tended to favor complex mathematical expressions of uncertainty, the framework itself is less quantitatively inclined as a result of its use of a weight-of-evidence approach to risk characterization. The U.K. DOE (*13*) framework stresses the need for assumption-based sensitivity analysis arising from the inevitable subjectivity of risk evaluations. The ANZ (*12*), NRC (*14*), and the Risk Commission (*17*) frameworks all tend toward less quantitative, more descriptive, expressions of uncertainty. The Risk Commission does not favor mathematical descriptions of uncertainty, arguing that assessments are decision-making tools, not precise analyses of actual or measurable risk.

The consequence of greater emphasis on deliberative processes and qualitative descriptions of risk is a move away from frameworks that execute analytical steps in strict sequential order. ANZ (*12*), U.K. DOE (*13*), and NRC (*14*) frameworks all allow numerous iterative loops beginning from any stage of the risk assessment/management process. These establish a series of continuously executed loops that refine rather than define the approach. The earlier MHPPE (*6*) and EPA (*7*) frameworks do not explicitly recognize iteration between analytical steps, although the proposed EPA guideline changes have specifically stressed iteration. They allow for limited iteration within steps and view monitoring as a quality control issue, not a trigger for assessment revision. In part, this is because earlier frameworks viewed assessment as a technocratic exercise dominated by logical, deductive processes. In contrast, later frameworks have stylized risk assessment/management as a largely deliberative decision-making process.

Deliberative processes by nature involve information exchange, refinement of views, and evolution toward a consensus. They are dynamic and should include feedback loops within and between analytical phases. The U.K. DOE (*13*) framework requires that risk decisions never be based on a single view of the facts, costs, or perceptions of a potential hazard. Newer frameworks have realized the importance of the "adaptive management" paradigm developed for renewable resource management (*18*). A lack of understanding of risk and inability to predict it precisely mandate a more cautious approach to management issues. More important, they point to the need to include human values, act prior to achieving scientific consensus, and confront the essentially political, social, and economic roots of environmental issues.

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