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A Guidebook to Comparing Risks and Setting Environmental Priorities

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Acknowledgments

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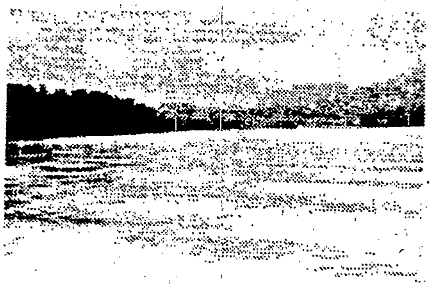

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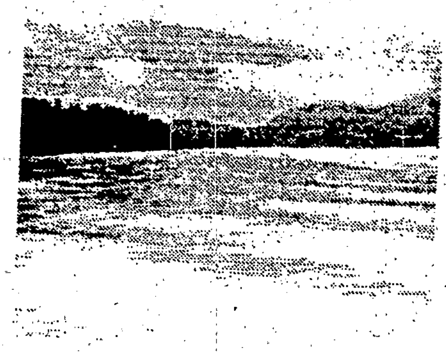


1.1 Introduction

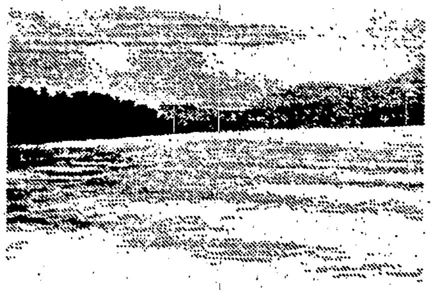
All environmental problems pose various types and degrees of risk to human health, to ecological systems, and to society's quality of life. Federal, state, and local government officials have found comparative risk to be a powerful management tool that helps them determine how to best allocate limited resources for reducing or preventing these risks.

Comparative risk is both an analytical process and a set of methods used to systematically measure, compare, and rank environmental problems. Besides helping managers identify the worst environmental problems—or the greatest risks—in their areas, comparative risk provides a common basis for evaluating the net benefits and costs of different strategies for reducing or preventing those risks. Thus, comparative risk rankings can provide an important input to the priority-setting and budget processes when possible risk reduction and prevention strategies are considered in the context of other relevant non-risk concerns, such as economic viability, technological feasibility, and social equity.

With the assistance of staff from the Environmental Protection Agency's Regional and State Planning Branch, comparative risk projects have been or are being conducted by over 20 states, several Native American tribes, and nearly a dozen localities. The comparative risk approach has also been applied in Bangkok, Thailand, Quito, Ecuador, and Tetouen, Morocco, and in other cities around the world, with assistance from the Agency for International Development.

This workbook provides guidance to those planning or participating in comparative risk projects. It discusses the major technical and managerial issues inherent in comparative risk projects; explains the mechanics of conducting the risk analysis and risk management phases of a project; and describes the international application of the comparative risk framework. As existing methods, data sources, and processes are adjusted or created in response to new applications of comparative risk, such as for urban or tribal projects, supplemental chapters will be periodically added to this workbook. These updates will be announced in the monthly bulletins of the Western and Northeast Centers for Comparative Risk and can be requested by anyone seeking them. They can also be obtained from the Regional and State Planning Branch office at EPA Headquarters in Washington, D.C.

In addition to this document, for those seeking advice or insights from others who have already conducted comparative risk projects, Appendix 2 of this document lists contacts and reference materials. Discussing questions or problems with others who have experience with the comparative risk process can be very useful in getting projects started successfully and keeping them running smoothly.



1.2 Creating a Strong Foundation

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The comparative risk process should be viewed as a whole, from data collection, analysis, and risk ranking to developing an action plan and implementing new strategies for reducing risk. Each comparative risk project is challenged to own the process, determine in advance how the information and rankings will be used, and determine how change can be initiated. The process is very labor intensive and politically charged. Because the investment of time and money is substantial, careful planning for the whole process is essential.

This chapter presents suggestions for planning a comparative risk project from beginning to end—setting goals, determining stakeholders, structuring the project, describing different external resources that are available, and highlighting a few issues that are important when getting started. The chapter ends with a list of activities for consideration from start-up to completion of a project.

Initiating a Comparative Risk Project

Most of the comparative risk projects to date have been initiated within state government, usually within the environmental protection/natural resource or health agencies. A few projects have sprung from the interest of environmental and business leaders; this trend will become more common as comparative risk becomes better known across the country. In either case, the initiator will find it useful to plan the process with a few of the key players or "stakeholders"; this group is referred to here as the project planning team. Potential stakeholders that might be considered as part of a comparative risk project team are listed in Exhibit 1.2.1.

Exhibit 1.2.1:
Potential Stakeholders of a Comparative Risk Project Team

- Governor's office
- State agencies
  - Department of Environmental Protection/Quality
  - Health Department
  - Natural Resources Department
  - Fish and Wildlife
  - Energy Department
  - Education Department
  - Agriculture
  - Land Use Commission
- Legislators
- Academics
- Major business interests
- Environmental advocates
- Reporters/media
- Chamber of Commerce
- Minorities
- Farmers/dairymen/ranchers
- Tribes

Some preliminary steps for the planning team are:

- Define the underlying problems (e.g., budget crisis, crumbling political consensus on priorities, possible mismatch of resources and needs, lack of clear mission or cooperation within and across organizations).

- Set goals for the project. Most project goals include making significant improvements in the policies. Meeting these political challenges should influence all other decisions about the project state's environmental management programs, including changes in priorities, budgets, and .
- Identify the individuals needed to achieve those goals, and create the comparative risk team. The team typically consists of a project director, steering and/or public advisory committees, and technical committees.
- Write a work plan. A work plan is one of the first products developed once the project's goals and objectives are identified. It should include the project's structure, budget, and methods.
- Develop ground rules; select analytical criteria and methods for assessing problem areas. The planning team may propose some ground rules, but typically the steering/public advisory committee(s) want to develop the ground rules. The technical committees are best suited to grapple with analytical criteria and methodological issues. They will have to decide which of the standard methods they will use and where they will try to innovate.
- Initiate the project with a kickoff meeting for the comparative risk team. After the initial planning and organizing, it is important to get the various committees started with enthusiasm and a shared sense of mission. Most states have found that assembling the participants off site (away from interrupting telephones and meetings) in a desirable and quiet location for at least two days has helped build a sense of mission and teamwork and a common understanding of the project ahead. Topics that are typically discussed in a kickoff meeting are indicated in Exhibit 1.2.2:

The planning team may need to repeat these steps several times before it will have assembled the correct group to set the project's final goals and objectives. At some point, the team may need to decide to push the project forward even though there may not be unanimous agreement on the project. There always will be skeptics or those resisting change. A key role of the planning team in the beginning is finding the right balance between building a strong foundation and knowing when to move on.

Building the Comparative Risk Project Team

There is no one right way to structure a comparative risk project. The types of committees and their roles and responsibilities will reflect the institutional and political realities in each state.

Though many variations are possible, the key organizational units and their responsibilities are shown in Table 1.2.1. These responsibilities are considered key because they represent basic functions that a person or committee should be responsible for in every comparative risk project. The members of these committees may need to change during the project to meet the changing technical and political challenges inherent in moving from an analysis of risks to the development and implementation of risk management strategies. Planners should determine these changes in advance. For example, the public advisory committee for the first phase (risk assessment) may be entirely comprised of interest group representatives, while in the second phase (risk management) it may be entirely comprised of legislators or state planners. However, most projects have maintained at least some continuity of membership (and, hence, ownership) in moving from the risk assessment to the risk management phase.

Exhibit 1.2.2:
Typical Kickoff Meeting Topics

- General background on purpose and goals of project
- Introduction of participants
- A ranking exercise--an opportunity to "get dirty" with the process
- Basic operational ground rules
- Basic training on how to conduct a human health, ecological, and quality-of-life comparative risk analyses
- Risk communication principles
- Vision of the project results
- Trouble shooting (Are all of the key stakeholders included in the project team? Does the proposed schedule mesh with timing requirements of the legislature? Etc.)

Table 1.2.1:
Key Organizational Units and Responsibilities of the Comparative Risk Project Team

Organizational Units	Responsibilities
Project Manager	Supervises all aspects of the project.
Steering Committee	Provides overall direction of the project.
Public Advisory Committee	Ensures public participation in the process, and ensures the project's work remains understandable, relevant, and credible to the public.
Technical Work Groups	Perform data collection, data analysis, and preliminary rankings.

Similarly, decisions such as who has ultimate responsibility for the final ranking of risks will also vary. Some states have chosen to give this responsibility to the senior managers (Steering Committee), while others have placed it with the Public Advisory Committee. Still another state created an Integrated Ranking Subcommittee, made up of three members from each technical work group, who had responsibility for developing a final integrated ranking of all problem areas. The key to success is making explicit decisions in the planning stage and then remaining flexible.

The functions and membership of the various committees can also be recombined in several ways. One project effectively merged the Steering and Public Advisory Committees. Another merged many of the functions of the Technical and Public Advisory Committees (with unknown results). While the four pilot projects in Colorado, Washington, Vermont, and Louisiana were managed directly by state government, some of the new projects are creating hybrid management structures with academia and consulting agencies. The complexity of these hybrids demands particular attention early in the process to defining clear roles, responsibilities, and expectations for turning phase one analysis into phase two action.

These ideas represent the best of what has worked so far, but each state project is unique. It is crucial to consider the roles, functions, and responsibilities that have been described and then to decide what arrangement will work best in each situation.

Major characteristics of the key organizational units from Table 1.2.1 are discussed in more detail below.

Project Manager

Role

The project manager choreographs all aspects of the project, is responsible for day-to-day management of the project, and is the principal contact with regional and Headquarters EPA. All state project manager positions to date have been full time.

Support

The project manager needs several types of support. Direct access to senior government officials (e.g., secretary of Department of Natural Resources or Department of Environmental Quality) and the support and commitment of senior managers within the sponsoring organization are critical. The project director will also need staff support as well as administrative support.

Responsibilities

The project manager maintains overall intellectual consistency and quality of technical analysis; may need to help direct research and edit technical reports; motivates committees and clarifies their options and responsibilities; and selects and directs consultants. He/she is responsible for ensuring that any necessary training is provided for project participants, including risk assessment, risk communication, and introduction to comparative risk training. The project manager helps ensure the project's transition from the risk assessment phase to the risk management. Responsibility for producing the comparative risk project report, which summarizes the risk assessment portion of the project; and other reports summarizing the action agenda or risk management phase of the project, resides with the project manager. He/she is heavily involved in "spreading the word" about the project. This may involve talking to the press and local civic and community groups, and writing speeches and articles. (For example, Colorado has developed a slide show to explain to citizens what the project was about and its results.) Other states have published newsletters to keep state employees up to date and involved. The project manager typically needs a variety of skills (e.g., writing and public speaking), a thorough understanding of state politics and the environment, and a strong sense of follow-through.

Steering Committee

Role

The steering committee provides overall guidance of the project and is involved in setting the goals and objectives. The steering committee may also be responsible for ground rules, major decisions, and final rankings.

Members

The steering committee is usually composed of directors or designees from all participating agencies, institutions, etc.; representatives from the governor's office; the chief or his/her designee from the Regional and State Planning Branch, EPA; and a representative from the EPA regional office. Major constituents to consider could include staff in environmental protection and natural resources, agriculture, housing, education, economic development, and transportation offices.

Responsibilities

The steering committee is ultimately responsible for the final rankings. They must obtain top management support to ensure enthusiastic participation at the staff level. They may be responsible for staff-hiring decisions and for building the technical work group members' responsibilities into job descriptions and performance evaluations. The steering committee is responsible for keeping the governor and other political leaders informed about and committed to the project. They are also responsible for setting the goals and objectives for the project, and for maintaining the organizational commitment to develop and implement the improved risk management decisions or budget changes. It is critical to engage the steering committee early in the process to ensure their support for the implementation phase; their involvement and support during this phase is essential to achieve project goals.

Public Advisory Committee

Role

The public advisory committee is the key liaison between the government participants and the general public and major interest groups. It provides a forum for the essential two-way communication about risk and public values.

Members

Committee members should be broadly representative of the state's regions, occupations, and interests. They should be known for working well with others to achieve common goals, not for being obstructionists. Typical members include state legislators, farmers, business leaders, academics, students, environmentalists, and representatives from minorities, tribes, and existing community networks.

Responsibilities

Some projects have successfully empowered the public advisory committee with full decision-making control over many major issues, such as defining an environmental vision for the state, selecting the set of problem areas, reviewing technical work groups' data and conclusions, and ranking the problems and recommending priorities. They have done this to ensure that the results do not become overly "politicized" and associated with a particular administration. The committee can also serve as an important source of continuity and commitment if elected or appointed officials change during the process.

One of the distinguishing features of the comparative risk process is that it allows for strong public participation. For those projects where involving the public is critical to accomplishing the goals and objectives, the initial planning should include a framework for involving public-interest groups, the general public, or the press. If details remain for developing and implementing a complete public-involvement strategy, then these issues should be addressed early in the process. How the public is involved is a specific matter for each project to decide for itself. Projects may involve the public early and often, soliciting their input on the problem areas to be studied, weighing public values, the appropriate ranking of risks, and action steps to reduce risks. On the other hand, the public advisory committee may be selected to represent the public during the risk assessment phase of the project, followed by public involvement through meetings or an environmental summit to share the rankings and solicit ideas for the risk management priorities for action. Whatever combination of events is decided, the important point is to involve the public and key stakeholders.

Technical Work Groups

Role

During the analysis phase of comparative risk, the technical work groups collect data; analyze the risks to health, ecology, and quality of life; and typically perform a preliminary risk ranking. In the risk management phase of the process, the work groups may develop and analyze a broad variety of strategies to improve the functioning of government, reduce risks, or reduce costs.

Members

The members of the technical work groups are typically experts from participating state agencies or they may be recommended by senior state agency staff. Work group membership may be augmented with other well-known outside experts, academicians, etc. Each technical work group should have a chairperson who is responsible for coordinating with the other work groups and ensuring the consistency and integrity of the approach, keeping the project manager informed of progress and unresolved issues, and ensuring that problem-area reports are completed on time.

Technical work group members may play a key role in defining the analytical methods to be used in the analysis, including selecting evaluation criteria, handling uncertainty, and presenting information. These roles will demand considerable judgment in addition to purely analytical skills. These issues should be addressed before and during the analysis, and may be reviewed and discussed with the steering committee.

Responsibilities

For each problem area, technical work groups develop plans of approach which briefly describe data sources, the chosen analytic approach (quantitative or non-quantitative), and major sources of uncertainty. They then conduct the analysis and write the problem-area report describing in detail the risk or damage estimates with discussions of analytic techniques, major assumptions, and sources and implications of the uncertainties imbedded in the analysis. Finally, work group members may develop preliminary or "straw" rankings and present these to the steering committee or public advisory committee.

Organizing the Work Groups

Because the technical tasks of a comparative risk project are so challenging, it is essential that projects create strong work groups with no weak links or reluctant participants. One state succeeded in building excellent technical teams by holding a competition for membership. Possible ways to structure the technical work groups are by risk type, by media, or by combining them into one large work group.

By Risk Type

Forming work groups according to risk type (human health, ecological, and quality of life) has several advantages. The first and perhaps most important is that this encourages communication among media offices, and begins to develop a multimedia orientation. Second, all work group members will become familiar with the data, analysis, and issues of all problem areas. This helps ensure a more balanced approach to the final rankings and is also a benefit to the individual members as they broaden their understanding of other areas.

By Media

Technical work groups can also be organized by media type (air, water, waste, toxics; or air, water, land, natural resources). This organization is appealing at first glance, since many agencies are organized this way. However, it doesn't encourage work group members to think in an integrated framework across programs and media, and there is a natural tendency for air members to rank air problems highest, water members to rank water problems highest, etc.

Single, Combined Work Group

A third option involves forming one large technical work group that does all three types of risk analysis (health, ecological, and quality of life). This structure may be useful where there isn't enough staff to form three separate work groups. However, this structure places a heavier workload on each work group member, and one or more risk types may not be treated fairly.

Targeting Available Resources

An ever-growing number of states, as well as all 10 EPA regions, have already completed comparative risk projects. Thus, states initiating a comparative risk project can draw on the experiences of these groups. In addition, other resources are available to assist those undertaking a comparative risk project. EPA's Regional and State Planning Branch, EPA's regional offices, and the Comparative Risk Centers offer expertise and technical guidance.

EPA's Regional/State Planning Branch

Regional and State Planning Branch (RSPB) at EPA Headquarters provides funding for each state's comparative risk project through a cooperative agreement. How these resources are to be spent is developed in the work plan and approved by RSPB, with concurrence by the regional office. Previously, states have used some of these resources to hire contractors or consultants to augment expertise within the state agencies. These may be contractors with previous comparative risk experience, or local experts or academicians familiar with each state's specific problems.

A staff person is usually assigned to each comparative risk project to provide technical assistance. This includes offering additional guidance on any of the issues discussed in this document, such as explaining how a state project fits in with EPA's planning and why this link is so important; briefing senior managers and/or staff on the project and relaying EPA Headquarters' response and perspective; recommending experts, or contacts in other states, for specific problems; suggesting the use of facilitators or mediators who have successfully led other states' meetings; and general brainstorming and problem solving. RSPB staff can also provide basic training that may be useful for work group members and assist in planning kickoff meetings and workshops.

EPA's Regional Offices

The EPA regional contacts can be an invaluable source of information and assistance. Those who have completed comparative risk projects can relate direct experience and provide detailed guidance and specific data. Also, any proposed changes in EPA funding of state programs that may occur as a result of this planning must be negotiated through the EPA regional office (although the amount of federal dollars will vary from state to state). It is therefore important to develop good communication with the region early in the project to ensure general agreement on major ground rules, analytic techniques, problem area definitions, etc.

Comparative Risk Centers

The comparative risk centers are staffed by a few former directors of state comparative risk projects and are funded by EPA (Office of Policy Planning and Evaluation). The centers provide technical assistance on comparative risk projects; they function as clearinghouses, providing information on what other states and regions are doing and gathering data from within EPA and other sources; they develop and conduct training courses for state project participants; and they also assist in technology transfer by hosting national meetings for state comparative risk participants.

At present, there are two comparative risk centers:

Northeast Center for Comparative Risk
Vermont Law School
P.O. Box 96; Chelsea Street
South Royalton, VT 05068
Ph. 802 763-8383; Fax 802 763-2920

Western Center for Comparative Risk
P.O. Box 7576
Boulder, CO 80306
Ph. 303 494-6393; Fax 303 499-8340

Initiating Activities Simultaneously

Although the process described in this chapter is presented "from start to finish," in many respects it is not a linear process. Several activities may be occurring simultaneously, and many issues may need to be revisited or revised during the project.

Project Planning and Start-up

- Assemble planning team
- Assess underlying problems
- Define goals for the project
- Secure support of key stakeholders
- Secure letter of support from the governor
- Select project director
- Determine organizational structure
- Select technical work groups and public advisory and steering committees
- Determine public-participation role
- Determine ranking process and who is responsible for each ranking
- Determine process to turn ranking results into risk reduction strategies/budget decisions
- Begin identifying and defining problem areas

Risk Analysis

- Finalize problem-area list and definitions
- Gather data
- Assess risks for each problem area
- Prioritize risks by ranking them
- Document risk analysis
- Identify areas of uncertainty requiring more research/data
- Identify environmental indicators that will help monitor risks in the future

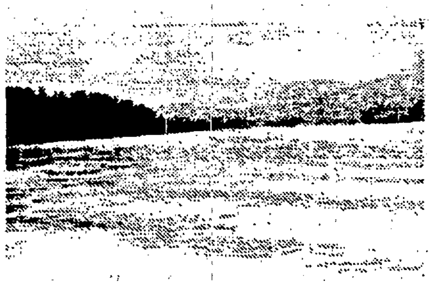
Risk Management

- Select risk management factors
- Determine risk reduction goals for problem areas
- Brainstorm on activities to reduce risk for problem areas
- Consider barriers to implementing activities
- Develop actions to overcome barriers
- Propose action plan—activities to reduce or prevent risk, a schedule, measures of progress
- Document action plans
- Establish process for repeating project or updating results

Project Wrap-up

Evaluate the successes and failures of the process for improvements in the next cycle—the process doesn't stop at the end of the project, but should be a foundation for years of incremental change and a more thorough understanding of the problems.

Risk Analysis Methods



2.1 General Analytical Issues

TABLES

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There is no single "correct" way to conduct a comparative risk project. Many approaches are workable, and each project should choose an approach that is uniquely adapted to its own political, institutional, and natural environments. However, regardless of which approach is taken, there are a number of important analytical issues and ground rules that should be resolved before beginning a comparative risk project. These include defining the organizational scope and analytical goals of the project, identifying the problem areas to be analyzed, determining the temporal and geographic scales for the analysis, and establishing methods and procedures for ranking problem areas according to the risks they pose.

This section discusses the advantages and disadvantages of various approaches to these issues, and makes recommendations based on past experiences. The decisions made concerning these issues will shape how the analysis is conducted and how the results can be interpreted and used. This section may therefore be of particular interest to project directors responsible for designing, directing, or implementing the project.

Defining the Goals of the Project

Project participants should strive to achieve a number of analytical goals aimed at ensuring a fair and open process. The following goals are suggested based on past experience with other projects:

Characterize All Risks Associated With Each Problem Area

Typically, risks are estimated quantitatively for only a portion of a problem area. The extent of the risks not encompassed in a quantitative analysis should be characterized or estimated non-quantitatively. This can be done by extrapolating the estimated risks from the portion of the problem area analyzed to the rest of the problem area. Or, conversely, risk estimates from larger studies, such as national air modeling studies, can be interpolated to the study area. Using information in this way can introduce more potential for error, which should be acknowledged, but it does allow the magnitude of risks to be estimated so that problem areas can be ranked into broad categories of high, medium, and low risks.

For example, there are hundreds of different toxic air chemicals in the atmosphere. In a typical comparative risk project, risk estimates would be developed for perhaps a dozen of the more common "air toxins." Analysts typically have to estimate whether this sample constitutes a large or small fraction of the total risk associated with the entire problem area. At the very least, the potential risks from the unanalyzed portion of the problem area should be described to risk managers so that their judgments about the risks are better informed, even if the magnitude of risk cannot be quantified or estimated. Decision makers may have to use their best professional judgment to adjust the assessment of an environmental problem to represent all the risks for that problem.

Be Consistent

To compare and rank the risks posed by different environmental problems, participants in a comparative risk project need to operate under a consistent set of definitions and analytical rules. For example, if individuals working on the project do not work with common definitions of the problem areas to be analyzed, then their ability to produce comparable results will be greatly diminished. Using different assumptions about exposure (e.g., assuming worst-case v. reasonable-case exposures) can also diminish comparability. Whenever it is not practical to characterize risks across problem areas consistently, then it is very important to warn those responsible for ranking problem areas of the potential effects on the results.

Be Explicit

Comparative risk projects should be as explicit as possible about definitions, methods, data sources and gaps, assumptions, participants, and procedures. Reports should contain information about the structure, procedures, and membership of the project, although some of the technical information might be contained in technical appendices. Any published reports should also explain the rationale behind decisions as well as the decisions reached.

Setting out assumptions can have several important advantages, such as:

- Helping current and future users and reviewers to better understand the strengths and weaknesses of the analysis.
- Creating a greater degree of trust among the public and affected special interests who are evaluating the analysis and the priorities developed from the analysis.
- Identifying gaps in existing data and areas where improved data are needed.

Conducting a comparative risk project highlights gaps in knowledge and data that decision makers must grapple with as they rank problem areas. Often, information that would be useful and desirable for assessing risks will not be available, or at best, it will be difficult to use in many cases. It is therefore necessary to use best professional judgment to complement the limited amount of hard data available. How this best professional judgment is introduced in the risk assessment and management process is extremely important. If it is introduced into the process in an unstructured way without reference to any supporting argument or experience, it can bias the outcome. This problem can be countered by having broad representation in the membership of the work groups and ranking committees. Good documentation of data gaps, assumptions, and use of judgment will aid in communicating the results of the project and translating them into action. Those reviewing and evaluating the findings of a project will have to accept the process used to reach them. If they do not accept the process, they will be unlikely to accept the product or conclusions. This type of thorough documentation can be of tremendous assistance in building trust and understanding among project participants, and between project participants and the general public. Comparative risk projects also provide an excellent opportunity to identify such gaps across the entire organization and to establish a priority list of research or data needs for the future. In some cases, new data should be collected; in other instances simply changing the way existing data is collected or stored may be adequate.

Distinguish Risk Analysis From Risk Management

While the relative ranking of a problem area is a key factor in setting environmental priorities, it is critical for project participants to understand that the risk rankings do not necessarily represent environmental priorities. Risk assessment asks the question, "What are the risks associated with different problem areas?" whereas risk management asks the question, "What solutions can be found to reduce the risks associated with different problem areas?" Risk management concerns need to be distinguished from estimates of the magnitude and nature of risks.

The aim of the risk assessment process is to evaluate and rank the relative magnitude of risks associated with problem areas on the basis of the best available scientific information and judgment. The risk-based rankings then serve as a key input to the risk management process in which a number of relevant non-risk factors (e.g., controllability of risks, legal mandates, public opinion, costs, etc.) are integrated with the risk rankings to set environmental priorities and select appropriate risk management strategies.

Addressing Environmental Equity Issues

Environmental equity has grown out of the concern that some low-income and minority communities are sometimes exposed to higher risks than other groups in society. Low-income and minority groups often live in polluted industrial areas where they may be exposed to multiple sources of risk. They also may not have the same access to health care services, making them more vulnerable to adverse health effects. For example, there are dramatic differences in the death rates, life expectancy, and disease rates of African, Hispanic, Asian, and Native Americans compared to the rates for Caucasian Americans. It is unclear how the combination of economic, social, cultural, biological, and environmental variables contributes to these disparities. However, the most important variables appear to be where one lives and their choice of life style (e.g., how much time they spend outdoors or what they eat).

In addition to the concern about low-income and minority groups, there may also be disproportionate risks borne by women, children, the elderly, and future generations. Each of these groups can be considered in a comparative risk project. By considering the special environmental conditions affecting specific populations and their unique vulnerabilities to environmental stresses, managers can implement efforts designed to protect them more effectively. Such consideration can be given to these issues during every phase of a comparative risk project.

During the Project Planning and Start-up Phase

Projects can be dramatically improved if they are inclusive of the full diversity of society. Since minorities are underrepresented in many federal and state environmental organizations and among public-interest environmental groups, it may be necessary to enlist the help of community groups, churches, and/or tenant organizations. During the planning and start-up phases of a project, many decisions are made that will frame the project and set the direction for how it is conducted. Therefore, it is very important that full participation occur from the very outset of the project, including the planning and start-up phases, and continue throughout the entire project. Early involvement in the project by all groups is likely to pay off at the end of the project in terms of broad-based public support to overcome any resistance to implementing the results of the project.

During the Problem-Area Identification and Definition Phase

Specific population groups that might be at higher risk can be identified in the problem-area identification and definition phase of a project. For example, the exposure of migrant farm workers to a multitude of pesticides may pose different and significant risks from risks posed to the general population. This may warrant creating a new problem area, or at least conducting a specific sublevel analysis of occupational exposure to pesticides within the larger pesticide problem area.

During the Risk Analysis and Ranking Phase

Differences in cultural behaviors, activity patterns, and food preferences among ethnic and racial groups can be analyzed, and may have implications during the ranking phase of a comparative risk project. For example, natural resource degradation can also directly have an impact on poor populations who traditionally supplement their diets by eating fish caught in possibly contaminated local waters. Different cultural values and norms can also affect how the quality-of-life analysis is conducted and which criteria are selected. For example, urban poor are likely to be more interested in enhancements to their immediate environment (e.g., urban parks and cleanup of abandoned industrial plants) than in preserving biodiversity or pristine natural resources in far-away places.

During the Risk Management Phase

This phase of a comparative risk project deals with the issues of what can and should be done about the environmental problems that were identified, analyzed, and ranked during previous phases of the project. Risk management strategies can be developed and implemented to address risks of particular concern to specific population groups. For instance, in some cases, due to their small population numbers in relation to the overall population, risks to specific groups (e.g., high exposures to pesticides among Hispanic migrant farm workers) are overshadowed by less severe risks to a larger number of people. Specifying early in the project that risks to specific populations will be explicitly analyzed, and that individual risk estimates (v. population risk estimates) will be considered in the risk management process, can help ensure that equitable actions are taken.

Defining the Scope of the Project

One of the first issues to be decided that will frame the overall analytic approach of the project is: Which environmental problems should be analyzed and which ones left out?

How far should the analysis venture into domains traditionally regulated by other health or natural-resource-management agencies? Should global problems be included in the analysis even though they are beyond the organization's ability to control them? In general, it is recommended that comparative risk projects be defined broadly to encompass all environmental issues and to capture potential future risks as well as current risks.

For the most part, comparative risk projects to date have combined analysis of traditional environmental problems (air and water pollution, waste, pesticides and other toxics, etc.) with other environmental issues where the authority to manage the problem is outside their purview (e.g., occupational exposures to toxic chemicals, land-use issues pertinent to habitat protection, and indoor air pollution). Projects that are more comprehensive typically require a greater degree of involvement by other relevant federal, state, and/or private organizations. This participation has contributed toward more cooperative working relationships among public agencies and between the private and public sectors.

Assessing Residual Risks

In comparative risk projects, risk assessments are performed on the risks that exist, given the efforts of public and private organizations to eliminate or prevent them. This "residual" risk approach provides environmental program managers with a view of their unfinished business and can help them set priorities for further risk reduction or prevention efforts. Environmental problems can pose risks to humans and ecosystems; they can also degrade the quality of life. Each type of risk is distinct and important. For example, non-point source pollution not only causes damage to ecosystems, it also causes large losses in recreational opportunities. Likewise, human or ecological risks from the accidental release of an oil tanker or a nuclear power plant can be calculated, but only a quality-of-life assessment can detect the impact on a community's peace of mind. Thus, it is important to look at environmental problems from each of these perspectives: human health risks, ecological risks, and risks to the quality of life.

Human Health Risks

These risks involve actual, estimated, or anticipated cases of human disease or injury caused by environmental problems. These include both carcinogenic effects, such as lung cancer from indoor radon, and non-cancer health effects, such as retarded mental development caused by ingesting lead in paint or soil.

Ecological Risks

These involve actual, estimated, or anticipated damages to the structure and function of natural ecosystems as well as to their biotic and abiotic components. Examples include: effects on animal and plant species due to eutrophication of water bodies caused by agricultural or urban runoff (i.e., non-point source pollution), fragmentation or loss of wildlife habitat, physical landscape modification and degradation, and reduced tree growth and increased susceptibility to pests in forests exposed to high levels of ozone.

Risks to the Quality of Life

Environmental pollution can also cause negative economic and social impacts. Quantifiable losses include increased maintenance costs of paint and other materials exposed to acid deposition, reduced recreational use of water bodies polluted by industrial discharges, the costs of replacing or treating contaminated water supplies, and the costs of medical treatment and lost productivity for individuals suffering adverse health effects. Non-quantifiable social losses include the sense of loss in community cohesion or cultural continuity, the anxiety of living near an environmental threat, the issue of intergenerational equity and leaving a degraded natural heritage to future generations, or the lost enjoyment value of open spaces.

Assessing Future Risks

As a priority-setting tool, comparative risk is more relevant to long-term strategic planning and budgeting if it captures a sense of both current and future risks. For example, a few environmental problems, such as global warming and the irreversible loss of habitat and biodiversity, may have potentially catastrophic consequences if actions are not taken in the short run to avert or minimize them. However, developing realistic and conservative scenarios of future conditions that are consistent across the full spectrum of environmental problems is fraught with difficulties and uncertainties. Fortunately, the differences in the magnitudes of various environmental problems are great enough that it is possible to reach consensus on a rough ranking of problems, despite these difficulties and uncertainties. For instance, the ecological effects and risks to human health due to waste-water discharges are relatively short term when compared to species extinction.

A number of different approaches can be taken to assess trends in risk. Trend analysis can use sophisticated fate and transport, demographic, or economic models, vast amounts of data, and intensive data analysis to estimate future conditions affecting environmental risks. However, trends can also be analyzed less quantitatively to determine whether a problem is likely to get worse, stay about the same, or improve over time. The ranking of problem areas can then be modified on the basis of informed judgments concerning risk trends.

The evolution of comparative risk has been to move away from assessing only current residual risks (i.e., a "snapshot" assessment) toward a more forward-looking analysis. Taking the synoptic or "snapshot" approach is analytically easier—it does not involve making future projections about contamination levels, exposures, or the effectiveness of future control programs. However, it ignores one of the most important aspects of risk: the changing magnitude of risk over time. Setting environmental priorities by focusing exclusively on the current level of risk has proven to be unsatisfactory in most cases.

In practice, it is difficult to be completely consistent in applying the same time frame to all problem-area assessments because of the different nature of environmental problems, the uncertainty of future conditions, and the availability of data. Some problems are of concern due to historical losses, such as wetlands or wildlife habitat losses, while other problems may pose only minimal current risks, but potentially catastrophic future risks. Therefore, some comparative risk projects have assessed current risks for many problem areas and future risk trends for a few well-studied (and modeled) problem areas such as global warming and stratospheric ozone depletion.

Analysts should be mindful of the time lags between the release of a contaminant into the environment and the ensuing health or ecological effects. For instance, cancer cells can become malignant and metastasize years, or even decades, after exposure to the contaminant. Conversely, some risk estimates may not reflect current risks as much as they reflect exposure to persistent contaminants that are no longer in use. For example, some of the more publicized and currently perceived risks from pesticides (e.g., high levels of DDT in lake trout, chlordane in crabs, eggshell thinning among eagles) are due to the persistence and bioaccumulation of pesticides used decades ago.

Discounting is a technique used in many financial calculations to account for the fact that the future value of a given amount of money is less than the same amount of money today due to inflation and the lost opportunity to invest the money. The same technique can be used to discount future health or ecological risks on the presumption that effects experienced in the future are less "important" than those same effects would be if experienced today. On balance, explicit use of discounting in comparative risk analysis raises difficult ethical issues and adds little in the way of precision. However, it is recommended that comparative risk analysts note in some way the time frame during which risks occur for all problem areas.

Whatever approach is taken, project participants are encouraged to consider all options and to be explicit about the choices they make so that everyone operates under the same ground rules. Single-point estimates of excess cancer cases or values calculated from a formula are simply not enough to characterize risks or rank problem areas. Decision makers also need to understand the uncertainties and assumptions that underlie each risk assessment. Two of the most important pieces of information they need to know are when the risk is present and how long it will persist in the environment.

Addressing Transboundary Effects

Defining the geographic scope of the project is one of the tasks that needs to be done before conducting the risk analysis. This involves deciding whether sources of pollution and their effects outside the area of the project should be considered and, if so, how they should be considered. Pollution from activities outside the project area, such as acid deposition from a neighboring state or region, can result in adverse health effects, environmental damage, and/or a diminution in the quality of life. In addition to these "imported" risks, some risks generated within the project area may also be "exported" to other states or regions. An example of this is the interstate transfer and disposal of hazardous wastes. The most important thing is to decide up front how these issues will be handled and to apply the approach consistently to the analysis of all problem areas.

Risks Imported From Other Areas

Pollutants move easily across political boundaries. As a result, risks can be imported from outside the project area or exported to other areas. The analytical issue is whether to analyze and "count" these risks in the risk analysis and ranking process. For some problem areas, such as hazardous waste treatment and disposal, estimating imported risks may be relatively straightforward because of tracking systems that are currently in place. However, for many air and water pollution problems it may be impractical to separate contributions from out-of-state sources. While the origin of the pollution may not affect the rankings of problem areas, noting the percentage of in-state v. out-of-state pollution can be extremely important information in deciding which risk management strategies to adopt and implement.

Risks Exported to Other Areas

The majority of state and regional comparative risk projects to date have chosen not to analyze and rank risks that are exported to other states and regions. While this may simplify the analytical requirements of the risk analysis, it may also result in missed opportunities to develop multistate or regional approaches to important environmental problems. In contrast, the Vermont comparative risk project attempted to analyze the risks it "exports" out of state (Vermont 1991). Even though they did not pose risks to the people and ecosystems within Vermont, project participants were concerned about the effects of their activities on other people and ecosystems outside of Vermont. A problem area called "Vermont's contribution to ecosystem degradation outside Vermont" was divided into two types of impact. The first type included risks that Vermont directly exports outside its boundaries, such as hazardous waste transported and disposed of out of state. The second type addressed risks stemming from goods and services Vermont consumes that are produced elsewhere. Because the consequences of Vermonters' consumption of imported goods and exported pollution are essentially unbounded, the problem area was not ranked, but was discussed in the ensuing report as an "underlying issue," along with unsustainable consumption and the impacts of population growth. Just by considering exported risks, Vermont's project participants hoped to make Vermonters more aware of their own contributions to national and global environmental problems.

Transboundary Effects on Migratory Species

Effects on migratory species present unique analytical problems in terms of how to characterize the size of the area affected. If a critical habitat of a migratory species is altered or eliminated, then a choice must be made about how to characterize the area of impact. One choice would be to consider only the actual area of disturbed habitat. Alternatively, the area of impact could be considered to be the species' entire habitat. (The monarch butterfly's annual migration to Mexico exemplifies this issue: Its winter habitat encompasses a small area in central Mexico. One approach would be to count only the area actually disturbed. Alternatively, the area of impact might be considered to be continental in scope since this would encompass the monarch's entire range.) In Vermont, if the only nesting of a species of migratory birds was eliminated, then it was considered to be a statewide impact.

Developing a Problem-Area List

Once decisions have been reached on the goals and ground rules for the project, then the first key analytical task is to establish a list of clearly defined environmental problem areas to be analyzed. This is a very important task because it affects how the analysis is conducted and may affect the risk-ranking results.

There are a number of alternative ways to generate a problem-area list. Given the different nature of environmental problems, there is no need for a single organizing approach. For instance, some problem areas, such as municipal waste water discharges to surface waters, are sources of pollution while other problem areas are specific chemicals or groups of chemicals, such as lead and asbestos or toxic air pollutants or pesticides. Still other problem areas are natural resources, such as ground water or wetlands, that are affected by a variety of sources and activities. Each approach offers different strengths and weaknesses, and the various approaches are not mutually exclusive. The fact is that most projects to date have used some variation on the programmatic approach and have adopted parts of other approaches to the extent that the resulting problem-area list and definitions made sense for their projects. Thus, project participants are encouraged to explore all options while learning from others' experiences.

There are numerous ways to create a problem-area approach, such as adopting existing lists from other state or regional comparative risk projects or soliciting citizens' views of an appropriate list. A reasonable approach might begin with brainstorming sessions among work group members, public interest and business groups, and scientists or academicians to generate many possible problem areas. In the initial phases, the process should be uncritical in that proposals are not subjected to rigorous scrutiny. This will encourage more creative thinking. It may also be advantageous to have more than one group generate a list of problem areas separately because different people will take different approaches and think in different ways about the task.

Once a fairly comprehensive or exhaustive list of problem areas has been generated, then it can be evaluated in terms of a number of desirable characteristics by a selection committee. If more than one group has generated a list, then these lists should be coalesced into a single list and evaluated. Potential criteria that can be used to evaluate a list of problem areas are described further on.

Using a group consensus process, problem areas can be added, removed, broken apart, or combined with other problem areas to generate a comprehensive and sensible list of problem areas that achieves the best balance among all the criteria that have been chosen by the selection committee. At this point, it is important that a common set of definitions is used to delineate what is included in and excluded from the description of each problem area. It will be difficult to draw conclusions from the project if work groups use different definitions of the problem areas.

It may be useful to solicit public comment once a tentative problem-area list has been agreed to by the committee. Comments can be solicited from other relevant state organizations (e.g., departments of transportation, tourism, economic development, and housing), regional EPA offices, public interest and business groups, and the general public through polls, focus groups, or public meetings. The committee can then consider these comments in its deliberations to finalize the problem-area list.

Desirable Characteristics

The following characteristics are desirable in designing a problem-area list.

- *Comprehensiveness.* The list of problem areas should encompass all of the environmental threats within the project scope. The list should also account for the fact that pollutants move across media (e.g., air pollution is a major contributor to surface water pollution). However, there is a trade-off between the ease of analysis and attributing all the cross-media damages to the relevant problem areas.
- *Consistent Level of Aggregation.* To make fair comparisons across problem areas, the areas should be defined at roughly similar levels of aggregation. For instance, if air problem areas are divided into several categories, then water problem areas should also be divided into a number of categories in order that ranking is not determined by the sheer size of a problem area.
- *Minimum Overlap.* It is desirable to minimize overlap between problem areas and the resulting "double counting" of risks. Overlap will occur when problem areas are not defined along a consistent dimension (e.g., by source or effect). However, since it is not a realistic expectation to use a single dimension for developing a problem-area list, trade-offs must be made between minimizing overlap and generating a list that is comprehensive, understandable to the public, and can be implemented. Double counting is further discussed below.
- *Ease of Analysis.* Some consideration should be given to the way data are collected and stored when problem areas are defined so that unnecessary difficulties in data analysis are avoided. For example, criteria air pollutants are often defined as a problem area because federal and state agencies, as part of their specific regulatory responsibilities, have collected data on these chemicals and compounds as a group. To break this problem area up into smaller parts or to add other chemicals to it may be warranted for other reasons, but it is useful to consider the implications of data analysis.
- *Ease of Implementation.* The purpose of conducting a comparative risk project is not to produce reports, but to use the information and insights gained from the process to reduce or prevent risks in the most efficient, effective, and equitable ways. Thus, an important consideration in developing a problem-area list is the relationship between problem areas and organizational structures that will implement risk management strategies.

- *Ease of Communication.* To be catalysts for action, problem areas need to be meaningful and understandable to the public. If problems that the public cares about are missing or are unintelligibly defined, then policymakers will have more difficulty communicating and implementing the results of the project.

In general, it is preferable to define mutually exclusive problem areas in order to avoid "double counting" the same risks in more than one problem area. This type of overlap results in overstating the actual risks for those problem areas at the expense of other problem areas. However, there are situations where double counting risks is not only unavoidable, but can be very useful in terms of balancing this criterion with other desirable characteristics, such as creating a problem-area list that makes sense and that is understandable to policy makers and the public. An example of this is provided by the dilemma posed by the ground-water problem area.

Ground water can be contaminated by numerous sources, such as pesticides, leaking underground storage tanks, salt/sand mixtures used to de-ice slippery roads, solid and hazardous waste sites, improper storage of hazardous materials at all sorts of commercial and industrial facilities, and residential septic systems. Questions arise as to how to allocate these risks. At first glance, counting ground-water risks in the problem areas where they occur would seem to be the best approach. For example, ground-water contamination associated with hazardous waste sites would be counted as one of the risks for the hazardous waste problem-area. However, it has been found from past comparative risk projects that ground-water risks become "lost" among a number of different problem areas as a result. This has created difficulties in communicating a comprehensive picture of the risks posed by and to ground water.

Due to the enormous public concern with contaminated ground water, some projects have created a separate "aggregated" ground-water problem area that describes the risks associated with ground-water contamination from all sources. However, the disadvantage of this approach is that by eliminating the ground-water contamination component from other problem areas (e.g., hazardous waste sites), a significant component of those problem areas is stripped away. The aggregated approach is used to avoid double counting the risks, but it may be very confusing to the public and difficult to explain why contamination of ground water caused by hazardous waste sites is not counted as part of the hazardous waste problem.

In response to the difficulties posed by the first two options, a third option has been developed that allows the risks of ground-water contamination to be traced back to its sources and counted in a separate problem-area that pulls all the sources of ground-water contamination together into one problem-area. The disadvantage of this option is that there is no attempt made to minimize the double counting of risks. In the relative-ranking process, this will tend to overstate the risks associated with ground-water problem areas at the expense of other problem areas.

Thus, each of the three options above offers advantages and disadvantages. There are no easy or "right" answers, but these types of decisions have important implications that should be considered carefully by project managers working with their technical advisors.

Alternative Approaches for Defining Problem Areas

Along Programmatic Lines

Most state health or environmental protection organizations are structured along media "program" lines (i.e., the air, water, waste, and toxics programs). In general, air programs tend to divide problems by pollutant type—radon, criteria air pollutants, and toxic air pollutants. Water programs tend to divide problems by sources—industrial, municipal, and non-point source discharges. Waste programs tend to differentiate between the types of sites, while toxics programs analyze individual chemicals or groups of similar chemicals. The differences are in large part due to the structure of individual statutes that authorize these programs. Table 2.1.1 illustrates the breakdown of problem areas using the programmatic approach.

Table 2.1.1:
Sample Problem Areas Defined Along Programmatic Lines

Water *(by source)*	***Air*** *(by pollutant)*	***Waste*** *(by site)*	***Toxics*** *(by chemical)*
Municipal & industrial waste-water discharges Non-point discharges Ground-water contamination Drinking-water contamination	Air toxics Criteria air pollutants Climate change Stratospheric ozone depletion Indoor air pollution	Abandoned hazardous waste sites Active hazardous waste sites Municipal solid waste Industrial solid waste	Lead in all media Pesticides Asbestos Radon Dioxin PCBs

Using a programmatic approach offers some important advantages, such as making it easier for program analysts to analyze environmental problems with which they are most familiar. It also allows project managers to quickly and easily identify individuals and offices with the requisite knowledge to analyze problem areas, and to hold them accountable for making progress to reduce risks. *EPA's Revised Core List of Problem-areas* has been included as Appendix A.

However, as EPA's Science Advisory Board pointed out in its critique of EPA's *Unfinished Business* report (1987), "the listed problem areas were not categorized in parallel [and] are much more attuned to programmatic considerations within EPA than they are to actual environmental problems in the real world.... Furthermore, the EPA list of problem areas is inconsistent with respect to the level of resolution of the classification" (EPA 1990b). For instance, active and abandoned hazardous waste sites are managed under different programs (i.e., RCRA and Superfund). This legal distinction concerning the status of ownership holds no special significance to the people or ecosystems at risk from such sites. In addition, the programmatic approach does not lend itself well to multimedia (e.g., air and water) effects or risks to human health or the environment from a variety of environmental problems in a specific area.

By Source Type

Defining problem areas by their source offers several advantages, but it does not work equally well for all problem areas. For example, this approach simplifies the task of analyzing risks for environmental managers and analysts because many environmental problems can be traced back to their sources. It is used to define many air and water environmental problems whose sources are easily identifiable. Unique insights can be gained by analyzing problem areas by source. For instance, instead of analyzing criteria air pollutants as a whole problem-area, one might analyze air pollution risks caused by mobile sources (e.g., auto, truck, and train emissions) separately from risks caused by stationary sources (e.g., power plants and factories). Table 2.1.2 provides an example of what a problem-area list would look like using this approach.

Table 2.1.2:
Sample Problem Areas Defined by Source Type

Water	*Air*	*Waste*	*Toxics*
Industrial & municipal waste-water discharges Agricultural practices Urban runoff Waste sites	Stationary sources Mobile sources (autos and trucks)	Household wastes Manufacturing waste products Retail wastes	Pesticides Industrial plants Household materials

Some environmental problems, such as global warming or ground-water contamination, are not easily defined in terms of their sources because they have a multitude of sources. It is easier and more logical to define them in other ways. For instance, indoor radon is a widespread and naturally occurring gas that can concentrate in homes whose designs inadvertently trap these gases. The important fact about radon is not its source but its presence in peoples' homes. Trying to define radon, or a number of other problems, in terms of their source can quickly become unwieldy and circuitous. However, as a general rule, tracing problems back to their sources is a helpful way to define problems.

By Pollutants or Stressors

Many public health and environmental protection organizations have programs to respond to risks posed by individual chemicals or "families" of similar chemicals (e.g., environmental lead and toxic air pollutants). Pollutants or stressors found in many comparative risk problem-area lists include pesticides, asbestos, and physical stressors to terrestrial and aquatic ecosystems. However, like all the other approaches mentioned, defining problem areas by pollutant or stressor works better for some problems than others. If an attempt is made to apply this approach to all problem areas, then it is quite possible that a number of problem areas will become "lost" or unrecognizable able to the public. For example, it is just more intuitive and easier to communicate a problem-area called ground-water contamination than to identify the problem by the pollutants and stressors affecting ground water. Exhibit 2.1.1 provides a partial list of problem areas that could be developed using this approach.

Exhibit 2.1.1:
Sample Pollutants and Stressors

- Hazardous organics & inorganics
- Gaseous phytotoxicants
- Ozone-depleting gases
- Chlorination products
- Nutrients, BOD, turbidity
- Microbes
- Physical stressors
- Thermal pollution
- Acid deposition
- Pesticides
- Lead, PCBs, asbestos

In the past, many organizations' activities have been focused on chemical stressors affecting human health, such as lead or radon. An emerging area of concern involves the ecological impact of physical stressors upon the environment, such as fragmentation of critical habitats caused by urban sprawl and highway construction. Examples of physical stressors include river channelization and water withdrawals, resort or recreational developments, and mining, timber harvesting, and range management practices.

By Affected Resource

The resource approach analyzes environmental risks in terms of the natural or cultural resources affected by various environmental problems. Because this approach is organized around resources, it has a geographic or spatial orientation that makes it particularly useful for understanding the ecological effects of environmental risks. Like other approaches, the resource approach is more suited to some environmental problems than it is to others.

Natural resources are typically divided into a number of categories, such as surface water, ground water, grasslands, forest types, critical wildlife habitats, and freshwater as well as marine, wetland, and estuarine ecosystems. Exhibit 2.1.2 provides a number of natural resource categories that can be used in comparative risk projects.

Exhibit 2.1.2:
Samples of Affected Resources

- Rivers, lakes & streams
- Oceans & coastal areas
- Estuarine areas
- Ground-water contamination
- Outdoor air
- Indoor air
- Open spaces
- Agricultural lands/topsoil loss
- Special areas/habitats
- Rare & endangered species
- Urban areas/cities

For instance, Colorado's comparative risk project included some unusual problem areas, such as open space, soil erosion, damages from changes in water quantity, and resources of special interest. The state of Washington analyzed risks to agricultural and range lands as well as the risks caused by those activities.

States planning to conduct a comparative risk project should consider using EPA's Environmental Monitoring and Assessment Program's (EMAP's) landscape characterization scheme for terrestrial ecosystems. EMAP is expected to become the primary monitoring and assessment system on the status and trends of natural resources for EPA and other federal agencies. States may become partners in EMAP by contributing and receiving information. Several states have already made significant commitments to EMAP, such as Pennsylvania and Illinois. Other states are considering how best to utilize this new program.

By Geographic Area

The geographic approach is very similar to the resource approach, but differs in that specific areas are selected as problem areas instead of ecosystem *types*. It is a way to match geographic areas to the specific stressors affecting them and to analyze the risks in a more focused way. The advantage of this approach is that it encourages a multimedia, holistic approach to environmental management in areas of special public concern and interest. The disadvantage is the inevitable double counting entailed and the requirement for better georeferenced data (i.e., data whose location can be pinpointed to a specific spot or area on a map). Exhibit 2.1.3 lists sample geographic areas.

Exhibit 2.1.3: Sample Geographic Areas

- Water bodies (e.g., the Great Lakes)
- Water basins (e.g., Chesapeake Bay)
- Airsheds
- Cites/urban areas
- Rural or open areas
- Protected areas (e.g., parks and preserves)

For instance, instead of analyzing risks to a certain type of forest in general, regardless of its location within the study area, specific forests of that type would be analyzed separately. The reason is that different forests, even of the same species, can be exposed to very different stress regimes depending on their location. The Guam comparative risk project is facing this issue (CDS 1993). Project participants there have to decide whether to analyze two separate and quite different coral reefs on either side of the island as a single problem-area (the "resource" approach) or as two separate problem areas (the "geographic" approach) because of the different stress regimes and risk management options that they pose to decision makers.

Specific geographic areas can be selected as problem areas on the basis of a number of factors, such as scarcity, vulnerability to stress, recovery potential and time, or because they are highly valued by the public. Usually, they are natural resources or areas of special interest and value. Entire water basins or specific wetlands, estuaries, lakes and bays, rivers and streams, or stretches of coastline can be selected as problem areas. Specific airsheds can also be identified so that risk managers can not only rank air problems but also target response actions geographically. Waste problem areas can be considered a single hazardous waste site if it is deemed important and visible enough that decision makers anticipate the public will ask what the specific associated risks are.

By Economic Sector

The sector approach analyzes risks to human health, the environment, and the social and economic quality of life caused by activities in different sectors of the economy. Thus, examples of problem areas using this approach would include those listed in Exhibit 2.1.4 This approach can be used in combination with other approaches by shuffling around different components of problem areas into economic configurations. By looking at risks from various angles, decision makers can gain new insights into the real "drivers" of environmental risk and develop more creative and innovative risk reduction strategies.

Exhibit 2.1.4:
Sample Economic Sectors

- Transportation
- Light manufacturing
- Heavy manufacturing
- Commercial development
- Residential development
- Energy production
- Waste-disposal industry
- Resort industry/tourism
- Road construction
- Silviculture
- Agriculture
- Military
- Non-military government

For instance, it is possible to combine the ecological impacts of a number of problem areas (such as non-point source pollution of surface waters, pesticides, soil erosion and sedimentation, and the physical alteration of terrestrial habitats) into a single economic sector (i.e., agriculture). By combining the risks associated with these problems and attributing them to a single economic sector, it is possible to gain an enhanced view of the full impact of agriculture on ecosystems. This approach can also be applied to human health risks from agriculture by looking at such issues as pesticide residues on food, pesticides in drinking water, and risks to farm workers. The main drawbacks of this approach are the overlap and potential double counting of risks among different sectors of the economy, and the somewhat artificial assignment of risks to a particular sector when it may actually involve several sectors sequentially.

Combining Different Approaches

The way that problem areas are defined has substantial influence on the nature of the solutions that are considered. Thus, it can be useful to use multiple approaches to problem-area definitions to generate a rich variety of potential solutions to environmental risks. After analyzing problem areas defined along programmatic lines, for instance, it is possible to reconfigure problem areas differently to answer questions, such as: Which particular pollutants seem to have produced the bulk of the risks for the higher-risk problems? Which particular sources are responsible for the bulk of the risks? Are large amounts of these pollutants or source types associated with particular economic sectors? Is there any information to indicate that risks are high in one particular geographic area? Table 2.1.3 from the Vermont comparative risk project demonstrates this relationship between the source and fate of stressors (Vermont 1991).

By defining or reconfiguring problem areas differently, it is often possible to understand the underlying causes or activities that create significant risks to human health, the environment, and to society's quality of life. Economic sectors, pollutants, or geographic areas can be used as organizational aids. For instance, from a management perspective, it may be very useful to understand the total impact from any of these perspectives. In addition, there is no reason why more than one dimension cannot be used in this type of analysis simultaneously, so that new insights about economic sectors, pollutants, and/or geographic areas are gained leading to more integrated risk management strategies.

Table 2.1.3:
Relationship Between the Source and Fate of Stressors

Stressors	Carbon monoxide/particulates	Greenhouse & ozone-depleting gases	Toxic metals	Persistent toxic organics	Volatile organic compounds	Oxygen-demanding wastes	pH-altering substances	Radioactive substances	Nutrients	Pathogens	Physical alteration of ecosystems
Stressors come from:											
Transportation	■	■	■		■		■				■
Energy production/consumption	■	■	■	■	■		■	■			■
Domestic and industrial wastewater treatment/disposal			■	■	■	■			■	■	
Farming/forestry practices					■	■	■		■	■	■
Hazardous waste disposal			■	■	■		■				
Solid waste disposal: landfill		■	■	■	■		■			■	■
Solid waste disposal: incineration	■	■	■	■	■		■				
Domestic and commercial use of toxic materials		■	■	■	■		■				
Construction and development activities	■	■			■						■
Stressors end up in:											
Ambient air	■	■	■	■	■		■				
Indoor air	■		■		■			■			
Drinking water			■	■	■					■	
Surface water			■	■	■	■	■		■	■	■
Ground water			■	■	■		■			■	
Soil	■		■	■	■		■	■	■	■	■

Source: *Environment 1991: Risks to Vermont and Vermonters.*

Agreeing on Risk Ranking Methods and Processes

One of the goals of a comparative risk project is to rank problem areas into different categories of risk. The process of ranking problems is difficult, however. Deciding which problems are most serious requires dozens of judgments about controversial facts, uncertainties, and values. Before ranking risks, it is important that all project participants, especially those actually performing the ranking, understand the importance of establishing criteria to rank problem areas, the summary nature of the rankings, and the difference between the risk rankings and management priorities. This section discusses issues involved in the process of ranking risks, presenting and evaluating different methods of ranking risks, and describing various presentation tools.

The Importance of Criteria

One way to make this difficult process more manageable is to discuss and agree upon a set of criteria for ranking problems. Criteria define what is important in thinking about a particular kind of risk. They also allow participants to make a series of incremental judgments, carefully piecing together an overall picture of risks, instead of making sweeping, complex judgments. Explicitly defined analytical criteria force participants to systematically think about their decisions and the underlying rationale. And only by being explicit about these incremental judgments can projects persuade other interested or affected parties that the process and its conclusions make sense and deserve attention. Regardless of which ranking methods and processes participants choose, or which criteria they select, the ranking process should be structured around a set of agreed-upon criteria.

The following example illustrates the importance of criteria. Two participants charged with ranking risks to human health may rank the risks from abandoned hazardous waste sites and criteria air pollutants very differently. Even though they may use the same facts to make judgments, their rankings of these two problems may be different because they used different criteria. One person may have focused on the total number of cases, and ranked abandoned hazardous waste sites low and criteria air pollutants high. If the second person was more concerned about the equity of risks—that no person should be exposed to significantly higher risks than anyone else—then they might have ranked hazardous waste risks higher than criteria air pollutants since the risks of hazardous waste sites are borne almost entirely by a small group of individuals living near the sites. Different criteria produce different rankings, so identifying them is critical to a successful ranking process.

Rankings as Analytical Summaries

In an ideal comparative risk project, the final risk rankings should be the most scrutinized and used but least important component. This is because the rankings are simply summaries of the analysis. If data are carefully collected and analyzed, analytical criteria articulated, uncertainties identified, and participants' values specified, then the ranking results should be fairly evident. Decision makers can use the rankings without reviewing all the information and judgments made by the ranking group. This also allows project participants to effectively explain and defend the results because the rankings accurately reflect the analyses and judgments they have made throughout the project.

The ranking process poses the ranking committee with a dilemma—how precisely can and should they rank the problem areas? The more distinctions they can identify, the more useful the rankings will be to decision makers and the public. All comparative risk projects to date have ranked problem areas into at least three groups, ranging from higher to lower risks. Most projects have used four or five groupings. Several projects have resisted labeling problems as "low" risks, since participants were concerned that readers would misconstrue the results as indicating that "low" problems are unimportant. In actuality, these problems are only "low" relative to the other problems analyzed by the project, rather than in any absolute sense.

What the Rankings Mean—Risks v. Priorities

Interpreting the rankings is typically one of the biggest sources of confusion during and after most comparative risk projects. What does it mean if a problem is ranked "high"? Will the organization devote more resources to it? Does it mean the problem is particularly difficult or easy to solve? Can an organization focus on lower-ranked problems, or should it reduce resources to those areas?

Such questions hinge on whether the rankings only reflect environmental risks or whether they are intended to convey management priorities. There is a reason why an organization's priorities may not correspond directly to the ranking results. Priorities must be set within the institutional, social, political, technological, and economic realities that can place real constraints on proposed risk management strategies. For example, a state public health or environmental protection organization may lack the legislative authority to address a certain environmental threat, there may not be any cost-effective technologies available, or there may be insufficient numbers of trained personnel to reduce the risk. These considerations as well as other risk management issues are discussed in Section 3.1.

Ranking Methods

There are three basic kinds of ranking methods: negotiated consensus, voting, and formulas. These methods form a progression from relatively unstructured to very systematic, structured approaches.

- *Consistency.* The method provides a consistent basis for comparing and ranking problem areas. For example, the use of secret ballots can lead to inconsistent results if participants ignore the evaluative criteria or apply them differently to different problem areas.
- *Fairness.* An open, inclusive process is encouraged and provides impartial redress procedures if bias is detected by anyone participating in the project.
- *Documentation.* This is important for the credibility of the project and ranking results. Participants must agree on a single explanation of what occurred in the ranking process (including recognition of disagreements and debates) so that others can better understand or reconstruct the process.

Negotiated Consensus

The objective of this approach is to reach agreement. Open discussion is often used, allowing the group to analyze and argue about data, values, and uncertainties in whatever way seems most natural. Some problems will receive intense scrutiny and debate, while others may be subjected to only cursory review. Although negotiated consensus is the least structured ranking method, most iterations roughly conform to the following steps:

- *Review data.* Participants present and discuss analyses of individual problems, answering questions about the risk estimates, analytic methods, and assumptions.
- *Take proposals for how individual problems should be ranked.* Participants then propose that problems be placed into a particular category of risk. Unless there is an objection or alternative, the ranking is not changed.
- *Briefly discuss objections or alternatives to proposals.* If the issue cannot be quickly resolved, then additional discussion is reserved for a later time. The group settles on

those problems over which there is general consensus on their placement in one of the risk categories.

- *Discuss and debate unresolved objections, and rank remaining problems.* The bulk of discussion is then focused on the remaining unresolved problems. In each case, discussion hinges on disagreements—clarifying positions, explaining criteria, and taking informal polls to monitor progress. Debate continues until consensus is reached.
- *Review results, employ other methods if necessary.* If consensus cannot be reached, then another method can be used to produce a ranking.

Some of the strengths of negotiated consensus are that the process is very simple, accurate, precise, explicit, and fair as long as discussion is vigorous and thorough. It also provides a healthy environment for the mutual education of participants since all participants can contribute equally. Once consensus is reached, group commitment to the results can be very strong.

One of the weaknesses of negotiated consensus is that it is occasionally difficult to keep participants focused on the agreed-upon criteria. Documentation can be difficult because discussion is typically fluid and wide-ranging (recorders can be very helpful in this regard). If the discussion is not vigorous and thorough, then the process may be inaccurate, imprecise, or unfair. This can be particularly true if there are very dominant or reserved personalities in the group; if the group is not diverse in skills, experiences, and beliefs; or if facilitators are not available to manage the discussion.

Voting

Voting is the most familiar and frequently used method of ranking problems. Recognizing that there will often be unresolvable disagreements, projects may resort to voting as a way to determine the majority's will. There are at least three different voting methods, some of which may be unfamiliar to participants. These include secret ballots, open voting, and multivoting.

In *secret balloting,* each individual has a single, secret vote to indicate how each problem should be ranked. Vote totals are then tabulated. Problems typically are ranked according to pluralities if no outright majority exists. If a problem receives seven "high" votes, four "medium" votes, and nine "low" votes, the problem would be ranked "low," even though a majority thought it should be ranked higher. An alternative approach that is more sensitive to differences of opinion would be to assign a value to each category (e.g., high = 3, medium = 2, low = 1). The arithmetic mean or average of the scores would then be used to determine where "natural" breaks in the distribution of scores occur so that problem areas could be placed into different categories of risk.

Open voting requires each person to identify his or her vote. Each person is given only one vote. Tabulation can be somewhat difficult with open voting, since participants may change their votes based upon what they observe from others. There are various ways to avoid vote-changing, such as having everyone vote simultaneously, or initially casting their votes in secret, revealing how individuals voted after the ballots are collected. Similar tabulation methods as described above for secret balloting can be used.

In *multivoting* all participant have the same number of votes. Participants can allocate their votes any way they prefer among the problem areas, although an upper limit can be set on how many votes can be assigned to a single problem. This method allows participants to express the intensity of their opinions. For example, if each participant is given 10 votes to divide among 20 problems, the group may decide to allow a participant to cast no more than 5 votes for any single problem. This prevents any one participant from having too much influence over the ranking of problem areas. Problem-areas are then ranked on the basis of votes received. Participants then usually use consensus, secret ballots, or open voting to decide where the breaks fall between the high-, medium-, and low-risk categories.

In general, voting is simple and fair in that all problems are voted upon, all participants vote, and each participant has the same number of votes. Because it is so easy to produce a ranking with voting, there may be a temptation to cut discussion off too early. This can cause the group to ignore complexity, magnify biases, and/or overlook data. Regardless of which voting method is chosen, methods are typically repeated several times during the project, or are used in combination. This gives participants a chance to explain their reasoning and persuade others to change their votes. In secret voting, participants are often asked to write down their reasons along with their votes in order to facilitate discussion and ensure that the agreed-upon criteria are being used to evaluate problem areas. In open and multivoting, participants who voted in opposite ways typically present their reasons. Revealing the sources of disagreement can often lead to agreement once the reasons for disagreement are clarified. However, some disagreements reflect differences in values or priorities among participants and may not be resolved. Multiple voting iterations can have the additional benefit of improving explicitness and record-keeping. When voting results cease to change with each iteration *and* participants have a clear sense of why the rankings came out as they did, the rankings are complete.

Formulas

Formulas share certain characteristics. Each attempts to manage the complexity of analysis by breaking environmental problems into parts. Each of these parts is then evaluated and mathematically recombined to produce an output. Formulas can be applied to the entire ranking process, or used only in particularly complex or difficult portions. Although it may not be apparent, it is important to recognize that value judgments play as large a role in formulaic approaches as they do in other less quantitative methods, since value judgments are needed to determine what criteria are useful, how they should be weighted, and how they are combined arithmetically.

For example, a work group composed primarily of health professionals could use negotiated consensus or voting to rank health problems and a formulaic approach to rank ecological and quality-of-life risks. Similarly, a group could use a formula to combine cancer and non-cancer human health risks for each individual problem and then vote to rank the problems in relation to each other.

There are a wide variety of formulaic approaches to ranking, but only one has been used in a comparative risk project to date. This approach is best described as "weighted scoring" and involves five steps:

1. Identify criteria for evaluating risks.
2. Score each problem for each criterion.
3. Assign weights to each criterion.
4. Multiply the criteria scores by the weights and sum the results to produce a total score.
5. Rank problems according to total scores.

In general, formulas have the following strengths and weaknesses: If properly constructed, they can provide the most accurate and precise rankings of any method. They are also very explicit about the relationships of different criteria, and are inherently fair, since the same criteria and equations are applied to. Formulas can also provide a clear record of how the rankings were generated. Poorly constructed formulas, however can produce inaccurate results. Generally, this is not because of mathematical errors, but because participants do not fully understand the consequences of their choice of weights and/or equations. Another weakness of formulaic approaches is the false impression of precision and level of understanding about risks to human health and the environment. In addition, while formulas can be very explicit about how ranking results were reached, they provide no insight into why the group chose certain criteria or assigned certain values to factors. Complex formulaic approaches may also be unfair to participants who do not have quantitative skills. Converting judgments and data to numeric scores requires that formulas be hypothesis-tested to ensure that they behave as intended. Careful thought needs to be given to the appropriate mathematical operations (i.e., summing, multiplying, or dividing) within a formula. Finally, complex formulas can be difficult for readers and users of the rankings to understand.

One formula developed by EPA's Region VI comparative risk project, the Ecological Risk Index Formula (ERIF), provides an excellent example of how a formulaic approach was used to rank the ecological risks of environmental problems in that part of the country. The ecological work group selected the following criteria as the most important factors in determining ecological risk, and used them to develop the ERIF: Area of Impact/Area of Ecoregion, Degree of Impact, and Degree of Vulnerability. Exhibit 2.1.5. depicts the formula that was developed by the work group. This relationship can be described in words as "the percentage of each ecoregion affected by a stressor multiplied by the severity of the stress multiplied by the vulnerability of the ecoregion."

Taking just one of the criterion for ease of explanation, "Degree of Impact" was calculated by analyzing the effects of different stressors on a number of important ecological functions such as the capacity of ecoregions to filter and detoxify pollutants. The next task the work group faced was to figure out how to objectively measure the degree of impact for each ecological function. Descriptions of various levels of impact were written for each function and assigned a numerical value. The resulting scale of impact, illustrated in Exhibit 2.1.6., describes different levels of impact on an ecoregion's ability to filter and detoxify pollutants from air, water, or soil.

Determining whether an environmental problem causes a Level 2 or Level 3 impact requires a great deal of professional judgment. There are no "hard" or entirely objective ways to make this, or many other, decisions without some level of subjectivity. In fact, attempts to remove professional judgment and experience from the process can prove counterproductive, as data and analytical tools are almost always inadequate to fully describe the nature and magnitude of risk. However, professional judgment can be incorporated into the process in a consistent and structured manner to minimize bias.

Exhibit 2.1.5: EPA Region VI Ecological Risk Index Formula

Summation over degrees of vulnerability

Summation over degrees of impact

$$ERI = \sum_{j=1}^{v} \sum_{i=0}^{n-1} AI_i/AE * DI_i * DV_j$$

Key Criteria

ERI - Ecological Risk Index
n - Number of Degrees of Impact
AI_i - Area of Impact
AE - Area of Ecoregion
DI_i - Degree of Impact
DV_j - Degree of Vulnerability
v - Number of Degrees of Vulnerability

The numerical values assigned for each score on every factor were then summed together to produce a "Degree of Impact" score for each ecoregion. These scores were then combined with the scores of the other two criteria (i.e., "Degree of Vulnerability" and "Area of Impact") to generate a total "Ecological Risk Index" (ERI) score for that problem-area for that particular ecoregion. The scores that were generated for all problem areas in all ecoregions then served as the basis for ranking the risks of problem areas and ecoregions; the scores did not completely determine the rankings. The work groups used the scores as a starting point for additional discussion and a more focused review of key data. Final rankings were determined on the basis of a consensus-building process, subject to the rule that any changes to the ERI rankings had to be explicitly justified in terms of disagreements over the scores assigned to factors.

Other Approaches

Among many other possible approaches to ranking risks, three that have not yet been applied to a comparative risk project hold promise: decision trees, decision analysis, and analytic hierarchy process.

Using *decision trees* as a variant of the weighted scoring method offers a more detailed way to reflect uncertainties. Whenever there is significant uncertainty about what score a criterion should receive, participants can lay out two or more possible scores and then assign a probability to each. In the Region VI example, each criterion was estimated with a single number. In some cases, these estimates may have been very uncertain. For example, the group could have identified a range of possible scores and their probabilities to reflect the uncertainty imbedded in their estimate of an ecoregion's diminished ability to detoxify and filter contaminants. Assuming that the group believed that the degree of impact ranged from a Level 2 to a Level 4 impact, and could agree to assigning probabilities to the different levels of impact, a decision tree reflecting the ecoregion's capability to filter and detoxify pollutants might look like Exhibit 2.1.7.

Exhibit 2.1.6:
Filtering/Detoxifying Scale for Degree of Impact

Level 1: Problem reduces assimilative capacity of the natural system through destruction of vegetation and microorganism populations.

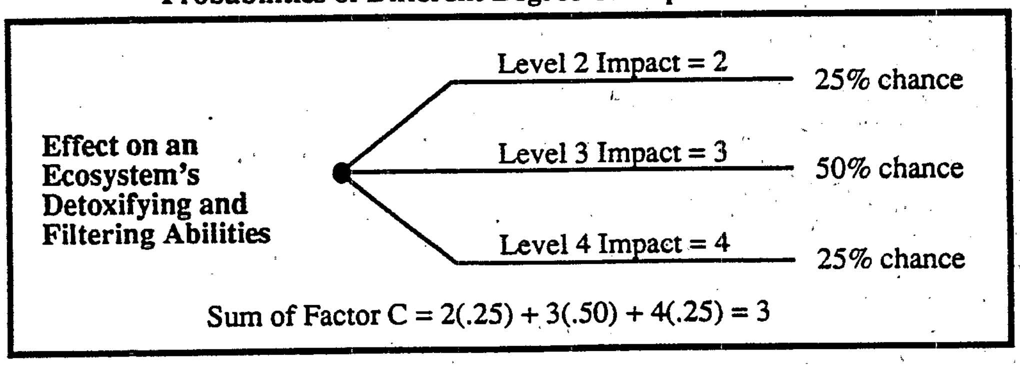
Level 2: Problem exceeds the assimilative capacity of the natural system for less than a year.

Level 3: Problem exceeds the assimilative capacity of the natural system for more than 1 year and less than 5 years.

Level 4: Problem continually exceeds the assimilative capacity of the natural system. Problem lasts more than 5 years but less than 50 years.

Level 5: Problem continually exceeds the assimilative capacity of the natural system for more than 50 years.

Exhibit 2.1.7:
Probabilities of Different Degree-of-Impact Estimates



Participants can then calculate a score and probability for each of these options. If the score changes significantly based upon these calculations, then the group will have identified a key variable that may merit additional research and discussion. By taking advantage of this approach's strength in bounding the uncertainty of estimates and forcing participants to consider the plausibility of various scenarios seriously, it leads to better-informed rankings. However, constructing a full-size tree (including all major criteria and uncertainties) can be exhausting and not always productive. In the Region VI equation, there are 78,125 possible combinations for the seven factors (each having a scale from one to five) for the "Degree of Vulnerability" criteria alone. However, the sum of these seven factors can only differ by 28, ranging from 7 to 35. Laying out the tree to discover which of the 78,125 combinations best fit the data could easily overwhelm the work group without affecting the ranking at all. This is an important reason why no project to date has used decision trees extensively. Decision trees would be most valuable where there are major uncertainties and where the interactions of uncertainties are too complicated for individuals to keep track of mentally.

Decision analysis incorporates many aspects of decision trees, but is more sophisticated. Decision analysis involves a complex set of rules and axioms for structuring problems, constructing elaborate decision trees, and modeling the values of participants. In addition to ranking problems, decision analysis focuses on identifying solutions to problems. A full description of decision analysis is beyond the scope of this document, but there are many source materials and practitioners at EPA, in academia, and among consulting firms.

Analytic hierarchy process (AHP) takes a different approach to ranking problems. In AHP, participants make many paired comparisons of problems. The basic principle behind AHP is that while ranking 20 problems may be complex, ranking 2 problems is much easier. If a group does enough paired comparisons, or "mini-rankings," in the right combinations, then a ranking of all 20 problems can be generated from them.

AHP also has the benefit of identifying inconsistencies in judgments. For instance, an individual might decide that air toxics pose higher health risks than solid waste, and that solid waste poses higher health risks than ground-water pollution, but that ground-water pollution poses higher health risks than air toxics. Inconsistencies like this (though usually less extreme) often occur when individuals are asked to process complex information. AHP highlights these inconsistencies and provides a more consistent approach to ranking. For this reason, AHP should not be attempted without guidance from an expert trained in its use. AHP has never been used in a state comparative risk project, but it has been used as a priority-setting tool for underground storage tank (UST) programs in several states and to rank Department of Energy defense production facilities.

Criteria for Choosing a Ranking Method

Each ranking method has different strengths and weaknesses. Evaluating a method in accordance with the following criteria can help identify the one that best meets the objectives of the project, and the needs and concerns of affected or interested groups. These criteria are:

- *Accuracy.* The relative ranking of the problem-area reflects the actual severity of the problem in the real world. For example, rankings can be inaccurate because of biases, uncertainties, and/or poor analysis or research.
- *Precision.* Problem-areas are ranked into as many categories as the data will support. Some methods can permit participants to make more distinctions than the data can support, resulting in false precision.
- *Explicitness.* The data, criteria, values, and uncertainties that go into the rankings are identified, along with the role each plays in the ranking process.
- *Simplicity.* Participants understand the ranking method and can communicate it to the public without undue difficulty.

All of the methods discussed above have been presented as if they were used individually to highlight their different characteristics. However, methods are not mutually exclusive and rankings are often arrived at by *combining approaches.* Using each method at different stages in a ranking process draws upon the strengths of each, while minimizing its weaknesses. Participants should feel free to create their own methods. Creating a unique ranking method can generate enthusiasm among participants and allow the group to tailor the ranking method to its own circumstances and needs. In creating a new method or mixing different methods, participants should keep in mind how the choice of method can influence the rankings.

Presentation Aids

The way information is presented to decision makers can profoundly influence how well it is understood and how it is ultimately used. Spreadsheets and specialized software programs are invaluable in building, running, and maintaining many large data bases and complex models. Using computers to do complex and large numbers of calculations allows participants to quickly and easily do analyses that would otherwise take many hours. For example, sensitivity analysis and "what-if" analysis can be especially important in distinguishing important factors from peripheral ones.

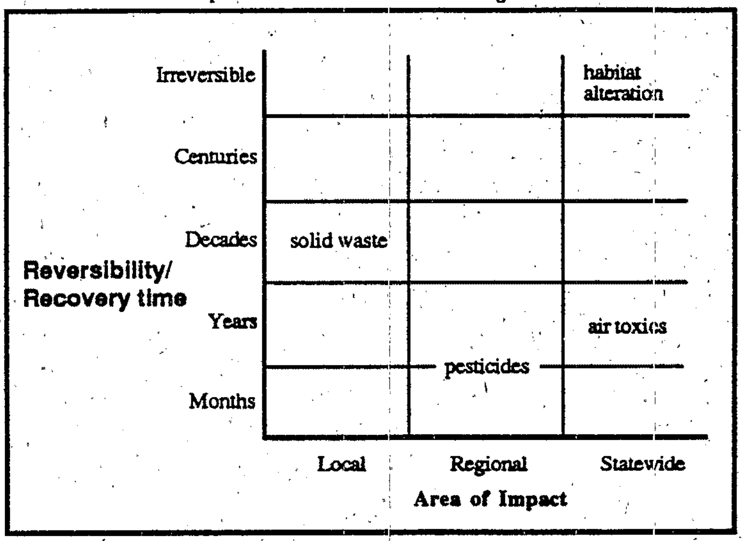
Matrices can be used with any method. A matrix simply presents two or more criteria on two axes. Its chief benefits are that it focuses participants' attention on the trade-offs between two variables at a time, is simple to construct, and provides an understandable visual record. Exhibit 2.1.8. illustrates a hypothetical ecological matrix.

If there are serious disagreements within the group, problems can be placed in more than one cell. This records disagreements that may require further discussion. In Exhibit 2.1.8., if only these two variables (i.e., reversibility/recovery time and area of impact) are used as criteria to rank the four problems listed, then habitat alteration would clearly be ranked highest. What about solid waste and air toxics problem areas? Ranking these problems would require a discussion about the relative importance of "reversibility" and "area of impact." Constructing a matrix can help promote discussion by clarifying the differences between problem areas and the relative importance of different criteria.

Individual or Combined Rankings

Almost all comparative risk projects to date have generated separate rankings for human health, ecological, and quality-of-life risks. Although ranking risks separately is laden with value judgments, combining rankings into a single ranking poses especially difficult challenges. Technical expertise and information are essential in analyzing whether one environmental problem causes more excess cancer cases per year than another problem. Technical information becomes less critical relative to the value judgments that must be made when combining cancer and non-cancer effects to rank human health risks. The values of the ranking committee's members are far more important than technical determinations made on the basis of supportable data when trying to create a combined human health, ecological, and quality-of-life ranking.

Exhibit 2.1.8:
Example of a Two-Criteria Ecological Matrix



If a group decides to combine rankings, then there are four basic methods: weighted scoring, negotiated consensus, voting, and rules. Combining rankings with weighted scoring, negotiated consensus, or voting works exactly as described earlier in this section, except that discussion and debate play an even larger role. The most critical information to combine rankings resides in participants' minds, not in any data bases or studies, because value judgments become even more important.

Combining rankings with rules involves establishing minimum requirements for a problem to be ranked in a certain way. A hypothetical rule might be: Any problem that is ranked "high" for two of the three individual rankings will be ranked "high" for the combined ranking. Another, more complex rule might be: A problem that is ranked "high" for any individual ranking will be ranked "high" for the combined ranking, if it is not ranked "low" for either of the other two individual rankings. Using rules to combine rankings usually has two consequences. First, the "high" group of problems ends up being larger than the "low" group, because groups often resist constructing rules that move problems down from their highest individual ranking. Second, the rules seldom dictate where every problem should fall. The ranking group must then use another method to complete the combined ranking.

Whether a ranking group should attempt to combine rankings depends on the mandate of the group. Senior managers may give the group clear authority to combine rankings. In these cases, the ranking group typically serves as a link to the public and the technical/scientific community. Senior managers may envision the project as providing guidance for some of the most difficult decisions and may want that guidance to be as comprehensive as possible. Another impetus for combining rankings involves how resources are allocated. Since an agency's overall funding is typically considered to come out of one "pot," this creates a desire to establish a single set of priorities to guide the allocation of those resources. The ranking team may be considered a good choice for the task, since it has grappled with these issues. However, this view or impression is often incorrect. Due to compartmentalized legislative authorities that tie the achievement of specific activity targets to funding, resources are often unavailable for other purposes. Thus, resources are not as "liquid" as they may seem because of the need for accountability to the authorizing/appropriating legal bodies.

In other projects, senior managers may envision the project as providing essential technical information in a useful form as an aid to setting priorities. In this view of comparative risk, the usefulness of providing technical information becomes less important as senior managers reserve the most important value judgments for themselves. Since combining rankings does not provide additional technical information to senior managers under this approach, and may distract the ranking group from its role as an evaluator of technical information, the group's mandate may be more limited. Therefore, it is very important that project participants receive clear guidance on how managers plan to use the project results since this decision will heavily influence how the ranking group views its proper role.

REFERENCES

Center for Development Studies (CDS), University of Hawaii and Pacific Basin Development Council. *Comparative Risk Analysis for Guam Environmental Protection Agency: Final Report.* Honolulu, Hawaii. January 1993.

Colorado. Department of Health and Department of Natural Resources. *Environmental Status Report: A Summary of the Technical Analysis of the Colorado Environment 2000 Project.* June 1990.

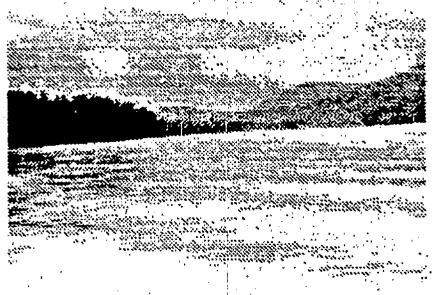
U.S. Environmental Protection Agency (U.S. EPA). Region VI Headquarters. *Comparative Risk Project,* Appendix A: Ecological Report. Dallas, TX. November 1990a.

U.S. EPA. Science Advisory Board. *Reducing Risk: Setting Priorities and Strategies for Environmental Protection.* Report by the Ecology and Welfare Subcommittee. September 1990b.

U.S. EPA. Office of Policy, Planning and Evaluation. Office of Policy Analysis. *Unfinished Business: A Comparative Assessment of Environmental Problems,* Appendix II. Washington, D.C. February 1987.

Vermont. Agency of Natural Resources. *Environment 1991: Risks to Vermont and Vermonters.* Report by the Public Advisory Committee, The Strategy for Vermont's Third Century. Waterbury, VT. July 1991.

Washington. Department of Ecology. *The State of the Environment Report. Environment 2010.* Olympia, WA. November 1989.



2.2 Assessing Environmental Risks to Human Health

TABLES

EXHIBITS

Risk is the probability of the occurrence of adverse effects. Adverse health effects are caused by exposure to harmful substances and can vary widely, ranging from lethal effects to more subtle biochemical, pathological, or physiological effects. Risk can be expressed quantitatively (probabilities ranging from zero to one) or non-quantitatively (low, medium, or high). To estimate the magnitude of the problem, the estimated risks to individuals can be multiplied by the estimated number of people exposed to the substance. EPA has defined human health risk assessment as:

> Evaluating the toxic properties of a chemical and the conditions of human exposure to it in order both to ascertain the likelihood that exposed humans will be adversely affected, and to characterize the nature of the effects they may experience (NAS 1983).

The traditional risk assessment process is comprised of four interrelated phases:

Phase 1: *Hazard Identification*—evaluating available evidence on the presence and hazards of substances likely to cause adverse effects.

Phase 2: *Dose-Response Assessment*—determining the degree of the effects at different doses.

Phase 3: *Exposure Assessment*—estimating the magnitude, duration, and frequency of human exposure to pollutants of concern and the number of people exposed via different pathways.

Phase 4: *Risk Characterization*—combining the information obtained from the hazard identification, dose-response assessment, and exposure assessment to estimate the risk associated with each exposure scenario considered, and to present information on uncertainties in the analysis to risk managers.

Applying Risk Assessment Concepts to Comparative Risk Analyses

Comparative risk analyses involve an additional component to risk assessments that entails comparing risks across problem areas to arrive at a relative ranking of the human health risks posed by the various problem areas. Since it is not usually feasible to conduct risk assessments for all pollutants and pathways associated with each problem area, comparative risk analyses have typically involved the following six steps:

- Selecting hazardous substances that are representative of those posing health risks for each problem area.
- Identifying typical exposure scenarios for the selected substances associated with each problem area.
- Calculating risks for those exposure scenarios using standard methods and readily available data on hazards and dose-response relationships.
- Extrapolating results for selected substances and exposure scenarios to the entire problem area.

- Comparing information on cancer and non-cancer risks for different problem areas to establish human health rankings.
- Combining cancer and non-cancer risks.

However, applying the risk assessment framework to comparative risk projects is not always a clear step-by-step process. It is more typically an iterative process in which the various phases are interrelated. For example, exposure pathways must be considered in all phases of the comparative risk assessment. In the hazard assessment phase, the potential hazards of pollutants are related to the likely exposure pathways, and the dose-response and exposure concentration of a particular substance depend on the route of exposure.

In addition, while standard methods for assessing cancer risks exist and can be directly applied to the comparative risk analyses, methods for assessing non-cancer risks and combining cancer and non-cancer risks are not well established. In adopting methods to individual problem area analyses, it is important to keep in mind the overall objective of the project, consistency among approaches to different problem areas, the time and resources available, and the analytic expertise of the staff.

The methods used to analyze problem areas are likely to vary because the types of data available vary. For example, if incidence data are available, then the response can be directly identified with no real need for traditional dose-response and exposure assessments. Similarly, if existing studies can be used to infer risks for a particular problem area, then the process is greatly simplified. There are basically three types of data that are commonly used in comparative risk projects: incidence data, data from other studies, and data from risk assessments. Table 2.2.1 lists the advantages and disadvantages of these three types of data.

Table 2.2.1:
Advantages and Disadvantages of Different Types of Data

Types of Data	Advantages	Disadvantages
Incidence data	Provides direct measure of adverse health effects. Eliminates need for risk assessments.	Not available for all problem areas. Cause and effect relationship is not always clear.
Data from other studies	Reduces time, resources, and expertise required to generate risk estimates.	Ambient concentrations, types of pollutants, and exposures may be very different and inapplicable.
Risk assessment data	Provides a direct measure of environmental ambient conditions and exposures.	Assumptions and uncertainties of models used can be large. More data and resource intensive.

Data on actual incidence of disease related to a given problem area are generally preferable to estimating risk based on exposure concentrations and assumptions about intake, potency, and the exposed population. For example, state studies may provide information on the statewide incidence of lead poisoning, or hospital admission data may provide estimates of the annual number of cases of pesticide poisoning in agricultural areas. These types of data can provide direct measures of human health effects, eliminating the need for extensive dose-response and exposure assessments. They also provide a better indicator of potential health impacts than exceedances of estimated safe levels. However, incidence data are not likely to be available for many problem areas. A related potential difficulty in using incidence data to characterize risks is that in many cases the data will not represent the geographic area in question, but instead a portion of the total geographic area or a broader area. In such cases, extrapolation or interpolation would be necessary to estimate the incidence for the relevant area. Another problem with using incidence data is that the relationship between cause and effect may not be clear. For example, lead poisoning can be caused by many sources of lead in the environment, including soil, drinking water, air, and lead paint. If an analyst is interested in knowing the risk of lead poisoning due to contaminated drinking water, then incidence data will not provide a satisfactory answer given the many potential sources.

For some problem areas, it may be appropriate to use existing studies from other states or countries to estimate either exposure or incidence. In many past state comparative risk studies, states have applied regional or national studies to estimate the risk to the population of their state. Because existing studies are likely to represent conditions in geographic areas other than those under consideration, actual pollutants and exposure conditions may be different from those analyzed in the existing studies. This presents difficulties in interpolating and extrapolating from existing studies to the relevant geographic area. The advantage of using existing studies to estimate risks is the reduction of time, resources, and expertise required. Existing studies should be reviewed critically to determine their relevance to the analysis at hand.

The third and most traditional approach to analyzing risks associated with particular problem areas is to estimate risks based on site-specific analyses of pollutants and exposures and, if necessary, adjust the results to estimate risks for that entire environmental problem. Monitoring data that indicate the ambient concentration of pollutants released into the environment typically serve as the basis for estimating human health risks. For example, past studies have estimated risks associated with a sample of representative hazardous waste facilities (e.g., landfills, incinerators), identified the number of facilities represented by each sample facility, and scaled up the estimated risks accordingly to provide a rough approximation of the total risk posed by hazardous waste facilities.

The advantage of this approach over the use of incidence data or existing studies is that it provides a direct assessment of existing pollutants and exposure conditions, rather than a questionable extrapolation of data derived under potentially different exposure conditions. The disadvantage of this approach is that typically it is more data and resource intensive.

Step 1: Identify Hazards

The first phase in human health risk analysis is identifying the hazard or potential risk. It is an initial screening step that broadly examines all possible sources, pollutants, and exposure pathways and identifies target pollutants, relevant exposure pathways, and adverse health effects associated with the pollutants and exposure pathways. Thus, it frames the scope of analysis for each problem area analysis.

Target Pollutants

Most environmental problems involve many hazardous substances. A comprehensive assessment of the risks from all toxic substances for each problem area would be unworkable in the context of comparative risk analysis, because of the size of the analysis and the resources required, and because of inadequate data on potentially hazardous substances. Therefore, the analysis of each problem area needs to be focused on a limited number of chemicals that best represent the actual risks.

A generic set of criteria for selecting target pollutants for comparative risk studies has not been developed. Primary factors to consider in selecting target pollutants include the inherent toxicity of the substance, its prevalence in the environment, and the likelihood of exposure. Information on structure-activity relationships, results of toxicity and biomonitoring tests, clinical studies, and epidemiology studies should all be evaluated as a basis for determining whether exposure to a substance can result in adverse health effects. Secondary factors include the availability of data needed to assess the risk posed and the level of regulatory concern for a particular substance.

In past comparative risk studies, the selection of target pollutants has been driven largely by the availability of data and expert judgment (which itself is a function of data availability and regulatory concern). Due to limited data and resources, many past studies have relied on too few target pollutants to adequately assess the risks (EPA 1990). Limiting target substances to less than five for problem areas with many pollutants introduces analytic biases that are very difficult to control and may be overlooked in the final ranking of problem areas. If such biases cannot be avoided by comprehensive hazard identification, then they need to be acknowledged and addressed on a case-by-case basis, adjusting the results to account for the unanalyzed portions of the problem wherever possible.

Relevant Exposure Pathways

Exposure to environmental pollutants can occur via many pathways and most problem areas involve more than one exposure pathway. Comparative risk analyses typically focus on exposures from ingestion of contaminated drinking water or soil and inhalation of contaminated air. However, ingestion of food contaminated by various means (deposition, plant uptake, bioaccumulation) and skin absorption by contacting contaminated surface water, shower water, soil, and air are important routes to consider. The exposure assessment can narrow the scope of exposure routes analyzed by focusing on those that clearly dominate others in the magnitude of potential risks that they pose.

Adverse Health Effects

Adverse health effects associated with target pollutants and exposure pathways are used to measure the severity of the effect. Adverse health effects can be divided into two groups:

cancer effects and non-cancer effects. Determining whether a substance poses a carcinogenic risk to humans is based on evidence from human epidemiological studies and long-term animal studies, as well as on other relevant information. EPA has developed a weight-of-evidence approach to classify the likelihood of human carcinogenicity. EPA's Integrated Risk Information System (IRIS) provides information on the weight-of-evidence groups for substances that have been evaluated by EPA. Based on human and animal evidence, supporting data, and data quality, substances are classified by EPA into one of the five groups described in Table 2.2.2 (EPA 1986).

Table 2.2.2:
EPA Weight-of-Evidence Guidelines

Group A:	Human carcinogen
Group B:	Probable human carcinogen
Group B1	Indicates limited human evidence
Group B2	Indicates sufficient animal evidence and inadequate or no human evidence
Group C:	Possible human carcinogen
Group D:	Not classifiable as to human carcinogenicity
Group E:	Evidence of non-carcinogenicity

Exposure to a given substance may result in a variety of non-carcinogenic toxic effects, depending on the dose. These may range from lethal effects to more subtle physiological changes. The toxic effects of a substance can vary with the magnitude, frequency, and duration of exposure, and the information needed to characterize the risks associated with particular exposure conditions. IRIS also contains information on non-carcinogenic health effects for some substances (EPA 1988). The effects from all available studies are considered in IRIS, but primary attention is given to the effect exhibiting the lowest "No Observed Adverse Effect Level" (NOAEL), the "critical effect." As discussed in the following section on dose-response assessment, this is the effect associated with EPA's estimated maximum safe levels (reference doses) for non-carcinogens.

Step 2: Assess Dose-Response Relationship

The relationship between the dose of a substance and the likelihood that it will produce an adverse health effect is essential in assessing the risk associated with exposures to hazardous substances. This relationship represents a substance's potency. EPA typically makes two general assumptions about dose-response relationships for particular substances:

- For carcinogenic effects, it is assumed that effects can occur at any dose, which are initiated by alteration of genetic material.
- For non-carcinogenic effects, it is assumed that threshold levels exist below which no adverse health effects will occur.

Because of this fundamental difference in the assumed dose-response relationships for carcinogens and non-carcinogens, the two are discussed separately below.

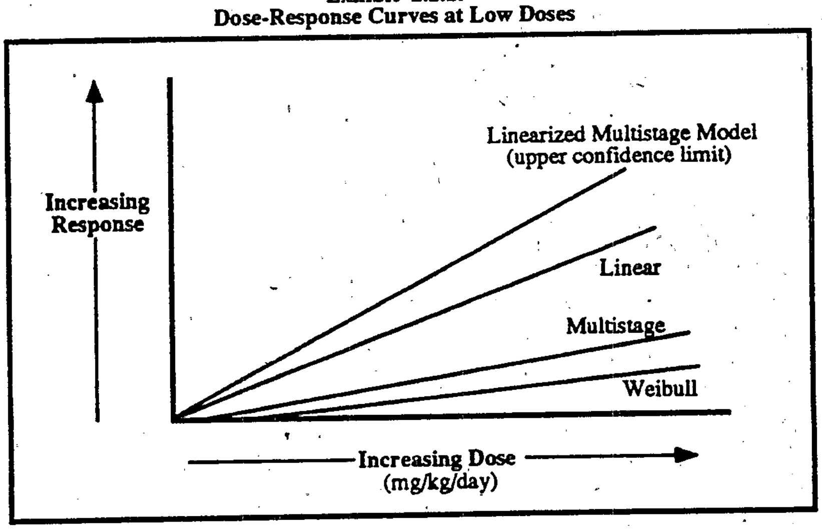
Dose-Response Functions for Carcinogens

Although the mechanisms of carcinogenesis (i.e., the alteration of genetic material) are not well understood for most chemicals, existing scientific evidence suggests that there is some probability of effect at any dose and that the cumulative probability of effect increases with increasing dose. Because the probability is low at low doses, it cannot be measured directly by either animal or epidemiological studies. Therefore, mathematical models have been developed to extrapolate from high to low doses. Extrapolation procedures typically define an upper bound by assuming linearity at low doses; EPA uses the linearized multistage model. Exhibit 2.2.1 presents a typical linearized multistage dose-response function along with other dose-response functions.

Determination of Cancer Potency Factors

Based on modeled dose-response functions, EPA has developed "cancer potency factors" and "unit risks" for many suspected carcinogens. Comparative risk analyses have typically used these potency estimates to assess the risks associated with exposures to carcinogens. Cancer potency factors (CPFs) express potency in terms of the risk per unit dose (milligram per kilogram of body weight per day, (mg/kg/day)), assuming lifetime exposure. CPFs are sometimes referred to as slope factors, as they are the slope of the dose-response curve. To estimate risk using CPFs, the CPF is multiplied by the estimated dose (or the concentration times the intake).

Exhibit 2.2.1:
Dose-Response Curves at Low Doses



Dose-response measures are also expressed in terms of risk per unit of concentration. These measures are referred to as unit risks and are multiplied by the estimated exposure concentration to calculate risk. The unit risk for air inhalation is expressed in terms of risk per microgram of toxin per cubic meter of air; whereas the unit risk for drinking water is expressed in terms of risk per microgram per liter of water. EPA's unit risk values assume an average body weight of 70 kilograms, an average inhalation rate of 20 cubic meters per day, and an average drinking water intake of 2 liters per day.

EPA's established CPF and unit risk values reflect the upper 95 percent confidence limit of the dose-response function estimated using the linearized multistage dose-response model. They do not account for the uncertainty inherent in the use of experimental animal data to estimate human responses. However, as long as these types of extrapolation assumptions are consistent for all pollutants and problem areas, the results provide a reasonable reflection of relative differences in risk as required in comparative risk analyses.

Availability of Cancer Potency Factors

EPA has established CPF and unit risk values for many chemicals that are common environmental pollutants. However, the list is by no means complete and is largely driven by the availability of toxicity data. The established CPF and unit risk values are available in IRIS, which is accessible on EPA's Electronic Mail or can be purchased from the National Technical Information Service (EPA 1988b). In addition, EPA's Carcinogen Risk Assessment Verification Work Group has proposed CPFs for chemicals not yet included in IRIS. If these sources do not provide CPFs for chemicals of interest in the comparative risk analysis, dose-response functions and their implied CPFs could be developed from animal toxicity data. In the past, however, this has been beyond the scope of comparative risk studies, and substances without established or proposed CPFs have not been evaluated for carcinogenic risk. If the expertise and resources are available to estimate dose-response functions from original animal or epidemiological data, it is important to ensure that the assumptions used are consistent with those used for generating other risk estimates.

Dose-Response Functions for Non-carcinogens

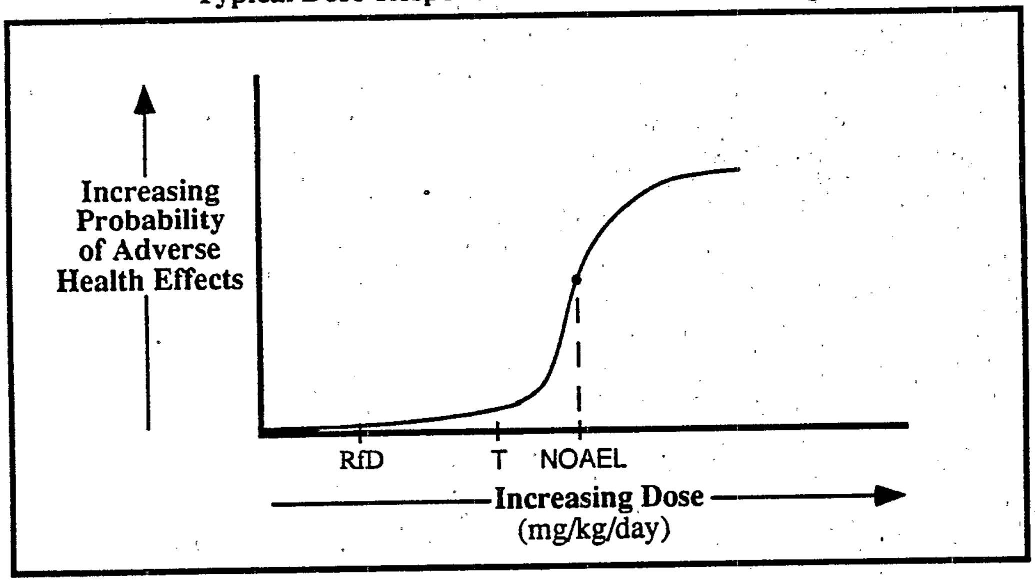
For biological effects other than cancer, EPA generally assumes that a threshold dose exists below which no effect will occur. Thus, the threshold is the minimum dose necessary to cause an adverse biological effect. The probability of an adverse effect occurring increases as the dose increases above the threshold level. However, the dose-response relationship above the threshold varies for different substances and types of exposures and is not well characterized for many substances.

For some non-carcinogenic substances, epidemiological data are available for certain exposure pathways. Studies of human health effects associated with criteria air pollutants, for example, have provided estimates of the number of cases of adverse health effects per unit concentration of ozone or particulate matter (EPA 1988a). Such estimates can also be used to estimate the expected incidence of adverse health effects.

Determination of the Reference Dose

In the absence of epidemiological data that characterize the dose-response relationships for non-carcinogens, an estimate of the threshold dose is typically used. Exhibit 2.2.2 presents a typical dose-response function for non-carcinogens (the threshold is designated by T). The threshold dose for a substance is approximated by the NOAEL, which is the highest dose at which no effect has been observed in toxicological experiments. A single chemical may exhibit more than one adverse effect, and the NOAELs for these effects may differ. The NOAEL for the health effect exhibiting the lowest NOAEL is typically used as the basis for estimating a maximum safe level.

Exhibit 2.2.2:
Typical Dose-Response Curve for Non-carcinogens



EPA typically develops a safe level, referred to as a "reference dose" (RfD), by dividing the NOAEL by an uncertainty factor; thus, the RfD will always be lower than the NOAEL. Uncertainty factors are based on the type and quality of the data from which the NOAEL was derived, and reflect the degree of confidence in the data as indicators of the human health effects of a substance. The RfD is defined as "an estimate (with uncertainty spanning perhaps an order of magnitude) of daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (EPA 1991). It is expressed in milligrams of substance per kilogram of body weight per day. In effect, RfDs are conservative estimates of threshold levels and are typically used as relative measures of the potency of exposure concentrations. As the magnitude of exposures exceeding the RfD increases, the probability of adverse effects increases. Therefore, the greater the RfD exceedance, the greater the human health risk.

It is important to note that RfDs (unlike CPFs) do not indicate the probability of adverse effects above the threshold; that is, one cannot extrapolate on a scientific basis between RfD exceedances and probability of effect. The dose-response relationship above a threshold level may be very different for different substances and types of exposures, but typically it is not well characterized or available for non-carcinogens. As a result, RfDs do not enable one to estimate risks at exposures greater than the RfD.

Despite this serious limitation of the RfD approach to characterizing the dose-response relationship for non-carcinogens, EPA endorses this method in its guidelines for quantifying non-cancer health effects (EPA 1991). In both *Unfinished Business* (EPA 1987) and all of the regional comparative risk studies, doses estimated from exposure concentrations were compared to RfDs (or some comparable standard) to characterize the risks associated with chemical exposures. The number of people exposed to doses exceeding RfDs was used to characterize population risks. Although other methods are currently under development, none is widely applied due to the preliminary nature and lack of data to support them.

Availability of Other Maximum Safe Levels

EPA has established RfDs for many chemicals that are common environmental pollutants. However, the list is not complete and is largely driven by the availability of toxicity data. The established RfDs are available in EPA's IRIS. In addition, EPA's Reference Dose Work Group has proposed RfDs for chemicals not yet included in IRIS. If RfDs are not available for chemicals of interest in comparative risk analyses, other regulatory standards that represent maximum safe levels can be used. In the past, EPA regions have used maximum contaminant levels (MCLs), ambient air quality standards, and threshold limit values (TLVs).

It is important to exercise caution in using alternative regulatory levels, since different standards may represent different degrees of conservatism. Inconsistencies in the bases of different regulatory levels should be adjusted for when interpreting results across substances and problem areas. For example, MCLs are not based solely on health considerations, but can include consideration of feasibility (cost and available technology). As a result, they may be less stringent than the health-based RfDs. Similarly, TLVs, developed for occupational exposures, are less protective than other health-based standards for general population exposures. It may be beyond the scope of the comparative risk analyses to make chemical-specific adjustments that put all threshold levels on a consistent basis, but the uncertainties associated with the use of maximum safe levels other than RfDs should be noted and factored into the final analysis.

Step 3: Assess Exposure

Exposure scenarios estimate the magnitude, duration, and frequency of exposure; the number of people exposed; and the intake of the substances to which people are exposed. These estimates can be generated directly from monitoring data of contaminant levels measured in the ambient environment and in biological organisms, or indirectly from modeling results or reasoned estimates. The steps involved in exposure assessment are:

- Identify significant exposure pathways.
- Identify sources and the location, timing, and quantity of pollutants released.

- Describe the concentrations of pollutants in the environment to estimate exposure.
- Describe potential human contact to estimate the number of people exposed to various concentrations via different pathways.
- Estimate human uptake via relevant exposure routes.

By evaluating these components of exposure, the analyst can construct reasonable scenarios for each problem area that characterize exposures to different populations. Exposure components are similar for both carcinogens and non-carcinogens.

Exposure Pathways

Humans are exposed to pollutants through ingestion, inhalation, or skin absorption. Activity patterns largely determine the routes of exposure. Standard assumptions that are used include the consumption of two liters of water per day and 20 cubic meters of air inhaled per day for the average adult. In actuality, studies have shown that there is a great deal of variability in these rates (EPA 1983, 1985). However, due to the relatively imprecise nature of comparative risk analyses and the magnitude of the uncertainties associated with other components, the degree of variability associated with intake assumptions may have a relatively minor effect on the overall results.

Most problem areas involve more than one pathway of exposure. To confine the scope of the analysis, the exposure assessment should identify the exposure pathways considered most important. For some problem areas, this may be straightforward. The primary exposure route for indoor air pollutants, for example, is inhalation. For other problem areas, such as hazardous waste sites, it may not be possible to limit the analysis to one pathway if the potential exists for exposure through drinking water, air, and direct contact. Many of the regional and state comparative risk studies focused attention on direct inhalation and ingestion exposures, and did not recognize less direct exposures. It is important to note that many comparative risk projects simplified the analysis by addressing less significant exposure pathways non-quantitatively and factoring them into the ranking process.

A complicating factor in the identification of relevant exposure pathways is that the toxicity of some substances may vary for different exposure routes. For example, asbestos is known to be carcinogenic via the inhalation route, but cannot be absorbed through the skin and has not conclusively been shown to be carcinogenic if ingested (Casarett and Doull 1980). Therefore, in identifying relevant exposure pathways, it is important to consider the toxicities of target pollutants via the different exposure routes under investigation. In the absence of relevant data on toxicity, metabolism, or absorption through different exposure routes, it is often assumed that adverse effects from different exposure routes are equivalent, but this assumption should not be made without proper consideration of available data.

Sources and Releases of Pollution

Information on the concentrations of released pollutants and their quantities is critical to estimating exposure concentrations, particularly where ambient monitoring data are not available. In addition, the location and timing of releases provides information important to determining likely human contact. For example, leachate concentration data at hazardous waste landfill boundaries is used to estimate the potential ground-water contamination in downgradient drinking water wells. Data sources for release information will vary significantly for different problem areas.

Fate and Transport of Pollution

Fate (the final destination) and transport (the route the pollutant takes) determine the pollutant concentrations that people are likely to be exposed to. These concentrations can be estimated using monitoring data or modeling. Monitoring data are clearly the preferred option, since modeling is usually based on numerous assumptions and limited data and may not provide accurate estimates of the concentrations to which people are exposed. Sophisticated mathematical modeling can also be resource intensive. Although monitoring data are preferable, this approach can also inaccurately predict human exposure levels, particularly if the estimates are only based on a few measurements.

In either case, it is important to consider the dilution/dispersion, mobility, persistence, and degradation of the substances in the environment prior to exposure. If the fate and transport of pollutants are modeled from release to exposure, such factors are particularly difficult and uncertainties increase due to the increased time and distance to exposure. Even if ambient concentration data are available, contaminant concentrations can change between the monitoring location and the exposure point. For example, drinking water concentrations at a drinking water treatment plant may not reflect concentrations at the tap, since other contaminants (e.g., lead) can be absorbed into the water in the distribution system. Such factors merit consideration in estimating exposure concentrations. In many comparative risk analyses, time and resources will constrain the use of sophisticated modeling of fate and transport, and reasoned assumptions will have to be made.

Human Contact

Estimating potential human contact with environmental contaminants involves evaluating activities that could result in contact, estimating the duration and magnitude of contact, and calculating the size and distribution of vulnerable populations. Using the exposure pathways defined for the analysis, this step identifies the numbers and types of people exposed and the range of exposures for each pathway. Census and survey data can be used to estimate the size of the exposed population.

In presenting information on the concentrations to which populations are exposed, it is important that the measures be consistent with the dose-response units used in risk calculations. Defining human exposures in terms of average daily exposures over a lifetime will enable the analyst to use dose-response data appropriate to chronic exposures. Similarly, acute exposure situations can be expressed in terms of average daily exposure over a short period.

For most problem areas, there will be a wide range of exposures, with some specific ethnic or socioeconomic groups being exposed to greater contaminant concentrations than others. For example, pesticide applicators will be exposed to far greater concentrations of pesticides than the general population. Similarly, people using private versus public drinking-water supplies may be exposed to different contaminants and concentrations. Behavioral factors will also affect exposure. Time and location patterns vary widely for different individuals. For example, some people spend more time indoors than outdoors, and people in some areas swim more frequently than those in other areas. In theory, for any chemical, there is a distribution of exposures that relates the size of the exposed population to the exposure concentration. To the extent possible, comparative risk studies should characterize potential exposures by identifying at least several points in the exposure distribution (e.g., a measure of central tendency and values one standard deviation above and below the median or mean value).

Some people may be more sensitive to particular contaminants than others and may experience health effects at concentrations lower than those causing adverse effects in the general public. In addition to integrating exposure and concentration distributions, the exposure assessment should attempt to evaluate the effects on highly sensitive populations, such as pregnant women, infants, or asthmatics. Another factor to consider is risk-mitigating behaviors. People may be inclined to reduce their exposures if they know they are at risk. If, for example, drinking water concentrations of benzene exceed taste or odor thresholds, some people will stop drinking the water, thus mitigating the potential risks. Consideration of these types of exposure variabilities will lead to more accurate risk estimates, but will not always be possible due to resource and data constraints. It is important to note that many comparative risk analyses have simplified the process either by not addressing all of the human contact issues for all problem areas or by only addressing them non-quantitatively.

Uncertainties

Estimating the exposure concentration, duration and timing of exposure, and the nature and size of the population affected are critical factors for characterizing human health risks. In many instances, the information available to assess these factors will be very limited, and time and resource constraints may not allow for the extensive analysis required to accurately evaluate them. For this reason, many of the factors discussed in this chapter cannot be thoroughly evaluated in comparative risk projects (Finkel 1990).

However, in almost all situations (particularly where data are limited and sophisticated analysis is not possible), the analyst will need to make various assumptions about and approximations of exposure concentrations, numbers of people exposed, and intake levels. It is important that such assumptions be consistent across problem areas and reflect a similar degree of conservatism. In most cases, it is possible on the basis of available data to estimate upper and lower bounds for exposure concentrations and numbers of people exposed. In some cases, statistical distributions can make it possible to do more sophisticated uncertainty analysis using Monte Carlo simulation techniques. At a minimum, a semi-quantitative or non-quantitative assessment of the impact of exposure uncertainties on risk calculations should be incorporated into the ranking process.

Step 4: Characterize Risks

In comparative risk analyses, risk characterization is the essential link between risk assessment and risk ranking. This phase involves combining the information obtained from the hazard identification, dose-response, and exposure assessment phases. It involves presenting information on multiple contaminants and exposure pathways in a way that allows decision makers to evaluate the relative risks posed by various problem areas. Because the risk characterization of carcinogens and non-carcinogens is different, they are discussed separately below.

Characterizing Cancer Risks

The most useful presentations of cancer risk estimates for comparative risk studies are excess individual lifetime risks and the excess number of annual cancer cases expected in the exposed populations. Population risk is an estimate of the annual cancer incidence. While many regional and state comparative risk studies have estimated both individual risks and population risks, most have relied primarily on the population risk estimates in the final ranking of problem areas for cancer risks. Both measures of cancer risk are discussed below.

In addition to numerical estimates of cancer risks, risk characterization helps risk managers judge the significance of risk estimates. In particular, information on the uncertainties associated with numerical estimates is critical to making informed ranking decisions. A framework for presenting such information is also discussed below.

Risk of Cancer to Individuals

Individual cancer risk is based on information provided by the dose-response and exposure assessments. It is calculated by multiplying the carcinogenic potency of the substance in question by the dose to the exposed individual:

Individual Cancer Risk = Potency (CPF) x Dose (Concentration x Intake)

The above equation assumes that the potency is expressed in terms of risk per unit dose (i.e., CPF), where the dose must be calculated based on the exposure concentration and the uptake or "delivered dose." If the potency is expressed in terms of risk per unit concentration (i.e., unit risk), then individual cancer risk is calculated by multiplying the potency by the exposure concentration. In this case, the potency estimate embodies assumptions specific to the route of exposure.

Individual Cancer Risk = Potency (Unit Risk) x Concentration

To illustrate the application of these equations, assume that an individual is exposed to 0.04 micrograms of beryllium per cubic meter of air inhaled. Using the CPF for beryllium of 8.4 per milligram per kilogram per day, and assuming an average intake of 20 cubic meters of air per day for the average 70-kilogram adult, the calculation would be:

8.4 (mg/kg/day)-1 x 0.4 ug/m3 x 20 m3/day ÷ 1 mg/1000 ug = 9.6 x 10-4

If the EPA unit factor for beryllium — 2.4 x 10-3 per microgram per cubic meter of air — is used, then the calculation is simplified to:

2.4 x 10-3 (ug/m3)-1 x 0.4 ug/m3 = 9.6 x 10-4

Individual risks can be calculated for individuals in various population groups. At a minimum, the comparative risk analysis should estimate individual risks to the average-exposed individual and the maximum-exposed individual. The average-exposed individual risk will reflect exposures to the majority of the exposed population. The maximum-exposed individual risk will reflect exposures to individuals exposed at higher concentrations.

If the same individuals are likely to be exposed to different carcinogenic substances or via different pathways, then the cancer risks associated with the concurrent exposures can be added to provide total individual risks for a given problem area. The assumption of additivity is a simplification that does not reflect synergistic or antagonistic effects that can occur between different substances. If concurrent exposures to co-carcinogens, promoters, or initiators are suspected, then they can be considered on a case-by-case basis.

Risk of Cancer to Populations

Population cancer risk, sometimes referred to as cancer incidence, is also determined by the dose-response and exposure assessments. It can be calculated by multiplying the individual cancer risk by the number of people exposed:

Cancer Incidence = Individual Cancer Risk x Exposed Population

This calculation can be made for specific populations and then summed to provide cancer incidence estimates for the total population. Air pollutants, for example, may pose greater risks to urban populations than rural populations. In this case, cancer incidence can be calculated for the urban and rural populations based on separate estimated exposure concentrations and populations, and then added to provide the total number of expected cancer cases for all exposed populations. As with individual risks, the analyst can assume additivity to combine population risk estimates for different substances and pathways.

Uncertainty

Presentation of numerical risk estimates without information on the assumptions and uncertainties underlying them can be misleading to risk managers. Therefore, it is important that such information be explicitly stated and considered in the risk characterization phase of the analysis. Explicit discussion of uncertainties and interpretation of the numerical estimates will provide the risk manager with insights into the accuracy and limitations of risk estimates. Major assumptions, omissions, scientific judgments, and estimates of uncertainty should always be included whenever characterizing risks. In addition, the appropriate weight-of-evidence designation should accompany the numerical risk estimate for any carcinogenic agent, indicating the degree of certainty of a substance's carcinogenicity.

For key factors, such as exposure concentrations and number of people exposed, uncertainty can be estimated quantitatively by using ranges of estimates in addition to a best estimate. Providing a range of risk estimates to decision makers enables them to determine whether the magnitude of the uncertainty warrants changing the problem-area rankings.

Presenting Cancer Risk Information to Decision Makers

Decision makers consider several different types of information when establishing a cancer risk ranking of problem areas. This information can be summarized and presented to decision makers in different ways.

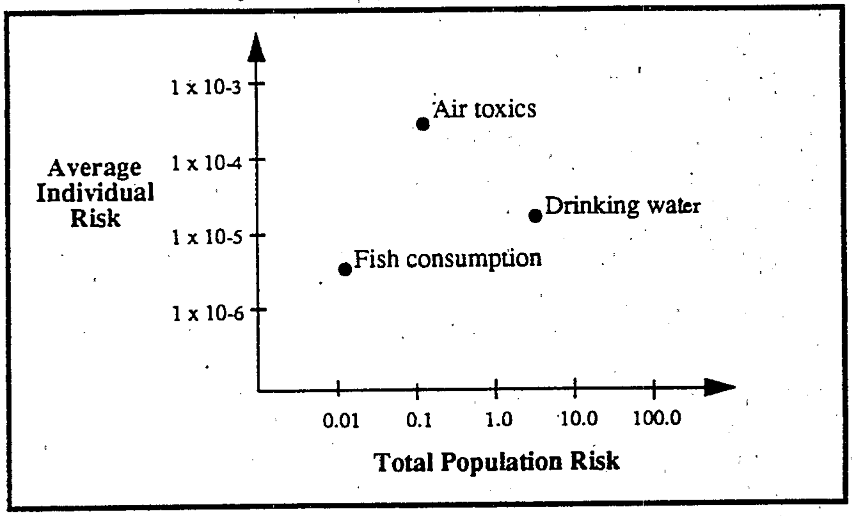
One basic presentation tool is a summary table (see Table 2.2.3) that combines relevant information on cancer risks and the analyses performed to derive them. Table 2.2.3 provides estimates of the average and maximum individual risks, total population risk or incidence, and risks to groups of highly sensitive individuals for each pathway, pollutant, and problem area. The comments column allows the analyst to communicate the limitations of the analysis, the major uncertainties associated with the estimates, and any biases these uncertainties may introduce. The analyst may also wish to present an aggregated version of this table by consolidating information on different pathways and pollutants within each problem area. This could be done by presenting ranges for the individual-risk metrics that include different pathways and pollutants and by adding the incidence estimates for different pathways and pollutants within each problem area. If the individual risks associated with different pathways and pollutants are experienced by the same people, they can be added to indicate the aggregated individual risks. Such a summary table should be used only to aid the ranking process and should not stand alone.

Table 2.2.3:
Sample Summary Table of Cancer Risks for Three Problem Areas

Problem Areas	Pollutant	Weight-of-Evidence Category	Average Individual Risk	Maximum Individual Risk	Total Population Risk	Sensitive Subpopulation Risk	Comments
Air toxics	Cadmium Beryllium 1,3 Butadiene Benzene	B1 B2 B2 A	3×10^{-6} 9×10^{-4} 3×10^{-4} 3×10^{-5} 12×10^{-4}	3×10^{-5} 2×10^{-3} 5×10^{-4} 6×10^{-5} 3×10^{-3}	0.09 9.00 4.00 0.42 12.51	0.06 4.00 1.00 0.12 5.18	Exposure concentrations based on 1988 monitoring data from two urban areas. AIR based on minimum recorded concentrations; MIR based on maximum recorded concentrations
Surface water (drinking sater)	Chloroform Bromadichloro-methane	B2 N/A	7×10^{-5} 5×10^{-5} 12×10^{-5}	--- ---	0.20 0.14 0.34	--- ---	Based on monitoring data from three drinking-water sources. May not be representative of state.
Surface water (fish consumption)	PCB Chlordane	B2	5×10^{-6} 2×10^{-8} 5×10^{-6}	--- ---	0.06 0.00 0.06	--- ---	Overestimate—assumes entire state population exposed by consuming 20 pounds of fish per year.

A second useful visual aid is a chart that combines information in a two-dimensional space on the relationship between two or more factors, such as individual and population risk. For instance, Exhibit 2.2.3 provides an example of a chart where each problem area is represented as a coordinate where lifetime individual risk is shown on the horizontal axis and annual cancer incidence is shown on the vertical axis. The coordinates indicate the relative risks posed by the different problem areas. It is important to note that the chart is simply a visual aid for presenting data to the ranking group and that the ranking itself should include other factors, such as sensitive subpopulations and uncertainties in the analysis.

Exhibit 2.2.3:
Sample Summary Chart of Cancer Effects



A variation of Exhibit 2.2.3 could illustrate the uncertainties associated with cancer risk estimates by incorporating ranges for individual and population risks. This can be done by drawing "bubbles" or "bands" around the point estimates. Visually presenting uncertainty in cancer risk estimates conveys the fact that reliance on best estimates is not sufficient to arrive at a ranking, or even a simple grouping of problem areas, since many problem areas will have risk estimates that overlap other problem areas.

Characterizing Non-cancer Risks

Past comparative risk analyses have characterized non-cancer risks according to three factors:

- Severity of the health effects
- Ratio of the dose to the RfD (dose/RfD)
- Number of people potentially exposed

Information on these three factors is generated in the corresponding first three phases of the risk assessment process. The risk-characterization phase involves summarizing and integrating this information into the incidence of adverse health effects for each problem area. This integrated picture provides the basis for ranking problem areas. The result is a complete picture of the estimated risks to exposed populations and specific subpopulations, in addition to explicit consideration of the uncertainties and critical assumptions in those estimates. Following is a discussion of methods for summarizing information on the severity of health effects, the ratio of the dose to the RfD, evaluating exposed populations, and choosing approaches to integrating the information across pollutants and pathways within and across problem areas.

Severity of Health Effects

The hazard assessment phase identifies the pollutants of concern for each problem area and the likely human health effects associated with exposure to those substances. In some cases, one substance may cause more than one health effect, or the severity of the health effect may vary with the dose of the substance. For example, cadmium can cause kidney dysfunction at low doses, kidney degeneration at higher doses, and birth defects at even higher doses. Rather than consider multiple effects for each pollutant, the analysis can focus on the effects that drive regulatory concern. In the case of non-carcinogens, this is the adverse effect that occurs at the lowest dose and is the critical endpoint on which the RfDs are based. The severity of this effect should correspond to the level of the estimated exposure concentrations.

Characterizing the severity of health effects is invariably controversial. Various severity scales have been developed, and most are highly subjective. The factors to consider in developing severity scales, or evaluating existing ones for use in comparative risk analyses, include functional effects, welfare effects, and the nature of the illness in terms of viability, reversibility, and manageability. Different scales emphasize different factors, and there is no universally accepted approach.

The approach developed for *Unfinished Business* (EPA 1987) classifies health effects according to their threat to the viability of organisms. A seven-point severity scale was developed as a guide to scoring the severity of health effects. The health effects and their position in this scale are presented in Table 2.2.4. The ultimate severity scores, however, took into consideration non-quantitative judgments about the extent to which health effects were permanent, reversible, and manageable. The severity scale was reduced to four groups for the final scoring.

One regional EPA project collapsed this scale even more by assigning all health effects to either high- or low-severity groups. The high group consisted of life-threatening effects, such as severe mental retardation and heart attack. The low group consisted of all other effects. The problem with this approach is that the range of health effects represented by low severity is very broad; thus, differences in effects, such as nasal irritation and emphysema, were not distinguished in the final ranking. Severity scales used in comparative risk analyses should ideally distinguish effects more finely than this. Others have suggested designating non-cancer health effects using three categories of severity: catastrophic, serious, and adverse. Table 2.2.5 provides an example of how this approach might classify different health effects into these three categories for ranking purposes. The placement of health effects in Table 2.2.5 is only for illustrative purposes and does not imply a recommended categorization, and the assignment of health effects into categories is likely to spark considerable debate.

Table 2.2.4
Ranking of Non-cancer Health Effects

Specific Effects	Score (1-7)	Specific Effects	Score (1-7)
CARDIOVASCULAR		LIVER EFFECTS	
Increased heart attacks	7	Hepatitis A	5
Aggravation of angina	5-6	Jaundice	4
Increased blood pressure	4	Increased weight	3
DEVELOPMENTAL		Increased enzymes	2
Fetotoxicity	6	Necrosis	6
Abnormal ossification	7	MUTAGENICITY	
Low birth weight	4	Hereditary disorders	7
Teratogenicity	7	Cytogenetic	4
HEMATOPOIETIC		NEUROTOXIC/BEHAVIORAL	
Methemoglobinemia	5	Sensory irritation	2
Decreased heme production	4	Convulsions	6
Bone marrow hypoplasia	5	Retardation	7
Impaired heme synthesis	4	Reduced corneal sensitivity	2
IMMUNOLOGICAL		Retinal disorders	4
Herpes	1	Visual aging	2
Allergic reactions	3	AChe inhibition	5
Increased infections	4	Learning disabilities	6
KIDNEY EFFECTS		Neuropathy	6
Tubular degeneration	5	Decreased sensory perception	3
Dysfunction	3	Irritability	3
Hyperplasia	3	Tremors	4
Hypertrophy	3		
Atrophy	4		
Necrosis	6		
RESPIRATORY		REPRODUCTIVE	
Emphysema	6	Post-implantation losses	4
Nasal irritation	2	Testicular degeneration	4
Pulmonary irritation	3	Spermatocyte damage	4
Nasal ulceration	3	Decreased testicular weight	3
Mucosal atrophy	3	Uterine hypoplasia	3
Bronchitis	4	Aspermia	6
Pulmonary impairment	4	Increased resorptions	4

Table 2.2.4
Ranking of Non-cancer Health Effects
(Continued)

Specific Effects	Score (1-7)	Specific Effects	Score (1-7)
Lung injury	4	Giant cell formation	2
Pneumonia	5	Increased spontaneous abortions	5
Pulmonary edema	6	OTHER	
Pontiac fever	5	Unspecified organ effects	
Congestion	3	Unspecified acute effects	—
Hemorrhage	4	Mortality	7
Alveolar collapse	5	Eye irritation	2
Fibrosis	5	Dental erosion	3
Nasal cellular irritation	2	Cataracts	5
Lung structure changes	5	Leishmaniasis	3
Aggravation of asthma	4	Adrenal	—
Increased respiratory disease	4	Gastrointestinal disease	4
Bronchoconstriction	4	Bone damage, dental mottling	2
Decreased mid-expir. flow rates	3	Symptomatic effects (headache)	3
Increased respiratory infections	4	Legionnaires' disease	5

Table 2.2.5:
Possible Health Effects Classification System

Catastrophic	Serious	Adverse
Death	Organ dysfunction	Loss in body weight
Shortened life span	Nervous system dysfunction	Hyperplasia
Severe disability	Developmental dysfunction	Hypertrophy/atrophy
Mental retardation	Behavioral dysfunction	Enzyme changes
Hereditary disorder		Reversible organ dysfunction

Ratio of Dose to RfD

Risks posed by non-carcinogens are typically characterized using the ratio of the dose of the pollutant to the RfD. This ratio is sometimes referred to as the Individual Exposure Ratio (IER):

$$\text{IER} = \text{Dose/RfD}$$

The IER represents the degree to which the dose of a hazardous substance exceeds the estimated safe level, and it roughly correlates with the probability of adverse effects at doses above the RfD. The greater the dose is relative to the RfD, the higher the ratio, and the higher the probability of adverse health effects. To calculate the IER, both the dose and the RfD must be in the same units since the ratio is dimensionless. This is typically accomplished by converting the exposure concentration (expressed in milligrams per liter of drinking water, gram of soil or food, or cubic meters of air) into a dose (expressed in milligrams per kilogram of body weight per day) using standard intake and body weight assumptions as illustrated in the following equation:

$$\textbf{Dose} = \textbf{Concentration} \times \textbf{Intake} \div \textbf{Body Weight}$$

For example, a methylene chloride concentration of five milligrams per liter in drinking water can be converted to an average daily dose, assuming an average drinking water intake of two liters per day and an average body weight of 70 kilograms, using the following equation:

$$5 \text{ mg/l} \times 2 \text{ L/day} \times 1/70 \text{ kg} = 0.14 \text{ mg/kg/day}$$

The reference dose for methylene chloride is 0.06 mg/kg/day; therefore, the estimated dose exceeds the reference dose by greater than a factor of two:

$$0.14 \text{ mg/kg/d} \div 0.06 \text{ mg/kg/d} = 2.38$$

There are important conceptual problems with using the IER to indicate the likelihood that an effect will occur above a ratio of one. First, using IERs to compare the risks associated with different chemicals implicitly assumes that the dose-response function for all substances is the same. That is, an IER of 2.38 for methylene chloride is equivalent to the same IER for all other substances. This clearly is not the case, as some substances may have a high probability of effect at this level while for others the effect may be negligible. This is due to the different responses of various chemicals, and different safety factors that are incorporated into the RfD. A second problem with the IER is that the assumed dose-response function is linear and indefinite whereas a true dose-response function would more likely be asymptotic, and the probability of the effect happening approaches one as the dose increases. As a result, using the IER as a relative measure of potency may lead one to make inappropriate distinctions between the potencies of different substances at high exposure levels. EPA recognizes these shortcomings and is currently developing alternative methods. However, toxicity data on non-carcinogens do not currently support biologically based human dose-response models at doses above some threshold such as the RfD (EPA 1991).

Evaluating Exposed Populations

Most comparative risk studies are unable to fully characterize the exposure distributions due to a lack of data or limited resources available to model the distributions. However, studies should attempt to describe at least several points on the distribution and, in particular, identify the population subject to potentially high exposure concentrations. In theory, for any chemical there is a distribution that relates the size of the exposed population to the exposure concentration. In general, there are large numbers of people exposed to low concentrations and smaller numbers of people exposed to higher concentrations. For example, urban populations may experience greater risk to certain air pollutants than rural populations. In this case, exposure concentrations and the number of people exposed should be specified for each subpopulation.

In addition, sensitive subpopulations (e.g., infants, pregnant women, and the elderly) should be identified, particularly in cases where the sensitive subgroup may comprise the only people in the exposed population who are at risk of suffering the adverse health effect. For example, children may be the only people at risk of lead poisoning from soil ingestion, or asthmatics may be the only people at risk from exposure to low concentrations of ground-level ozone (i.e., smog). To fully characterize the risks associated with each problem area, these sensitive subpopulations should be specified.

Knowing the number of people exposed to a particular contaminant is critical to characterizing population risks and is often difficult to estimate. Census data can be used to identify and describe exposed populations where more accurate state or local data are not available. Whatever information is used is likely to be somewhat uncertain. Therefore, to characterize the uncertainty, it is best to characterize exposed populations using ranges of population estimates.

Presenting Non-cancer Risk Information to Decision Makers

As suggested by the preceding discussion, decision makers must consider many different pieces of information when establishing the non-cancer risk ranking. Ways of summarizing and presenting this information to decision makers to ensure that all relevant factors are taken into account are presented below. The ideas given here are merely suggestions; analysts should develop tables, charts, and other materials that best communicate the non-cancer risk information to decision makers.

One basic presentation tool is a summary table that gathers together relevant information on non-cancer risks. Table 2.2.6 provides hypothetical estimates of the dose/RfD ratio, the number of people at risk, and the severity rating of the health effect for each pollutant, pathway, and problem area. The comments column allows the analyst to communicate the limitations of the analysis, the major uncertainties associated with the estimates, and the biases these uncertainties may introduce. The analyst may also wish to present an aggregated version of this table by consolidating information on different pollutants within each problem area. This could be done by presenting ranges for the dose/RfD ratio, population at risk, and severity. Alternatively, the estimates for each of the factors could be added or averaged as indicators that represent the entire problem area. A third approach would be to select the pollutant thought to pose the greatest risk or only those pollutants with IER ratios of greater than one. In any case, an aggregate summary table should be used only to aid the ranking process and should not stand alone.

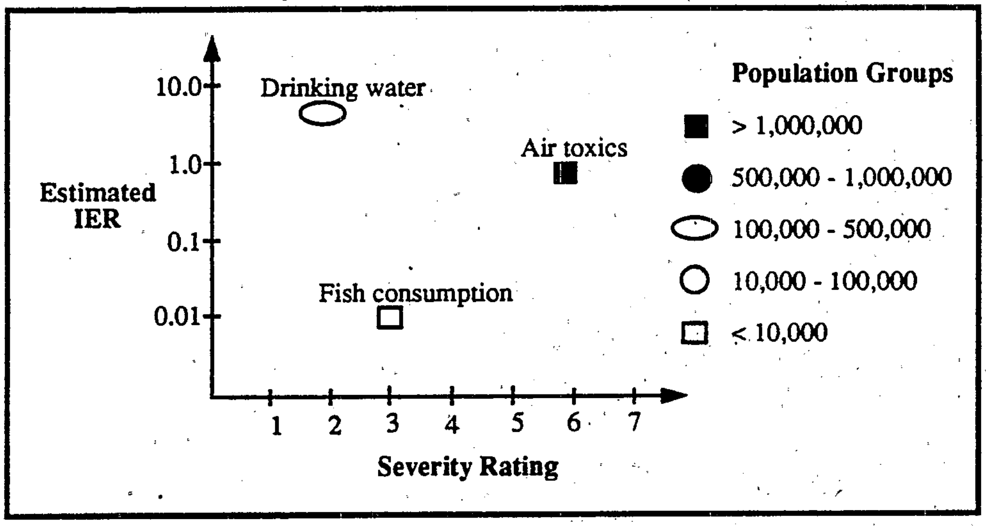
Another useful visual aid is a chart that combines information on several factors in a two-dimensional space. Exhibit 2.2.4 below on non-cancer health effects is analogous to Exhibit 2.2.4 on cancer health effects. Exhibit 2.2.4 shows three problem areas as coordinates on a chart, where the severity ratings are shown on the horizontal axis and the estimated IER is shown on the vertical axis. The shape and shading of the points represent the estimated number of people at risk for each problem area.

Table 2.2.6:
Sample Summary Table of Non-cancer Risks for Three Problem Areas

Problem Areas	Pollutant	Dose/Response	Total Population at Risk	Severity (rating)	Comments
Air toxics	Cadmium	0.00 - 0.02	800,000	Pneumonitis (4)	Exposure concentrations based on 1988 monitoring data from two urban areas. Dose/RfD range based on minimum and maximum recorded concentrations.
	Beryllium	0.02 - 0.03	800,000	Pneumonitis (4)	
	Toluene	1.14 - 2.21	800,000	Neuropathy (3)	
Surface water (drinking water)	Chloroform	2.51 - 3.42	250,000	Cyst formation in liver (3)	Based on monitoring data from three drinking-water sources. May not be representative of state.
	Bromadichloro-methane	0.01 - 0.29	250,000	Renal cytomegaly (3)	
Surface water (fish consumption)	DDT	0.00 - 0.04	800,000	Liver lesions (3)	Overestimate—assumes entire state population exposed by consuming 20 pounds of fish per year.
	Chlordane	0.00	800,000	Liver hypotrophy (3)	

Note: Uncertainties associated with estimates of dose/RfD and population can be illustrated equally well in a table or chart. By incorporating uncertainty "bands" or "bubbles," either a table or a chart can convey the fact that reliance on point estimates is not sufficient to arrive at a ranking since many problem areas will have estimates that overlap with other problem areas boundaries.

Exhibit 2.2.4:
Sample Summary Chart of Non-cancer Effects



STEP 5: RANK CANCER AND NON-CANCER RISKS

Once the results of the risk assessment have been characterized for each of the problem areas, then decision makers will need to rank them based on the estimated human health risks that they pose. However, a simple ranking based on quantitative risk estimates is not possible for several reasons. First, many different metrics are used to describe human health risks and cannot be directly compared. Cancer and non-cancer risk metrics are particularly difficult to combine. Second, quantitative risk estimates are subject to considerable uncertainty, resulting in wide ranges of estimated risks. The overlap in these ranges often precludes a simple ranking. Finally, there are many uncertainties in risk estimates that cannot be quantified, but which warrant consideration in the ranking process.

Due to the difficulties in combining cancer and non-cancer effects in a single ranking, approaches for separate rankings are presented below. Suggestions for addressing non-quantitative factors, such as severity of effects and uncertainties in the ranking process, are also presented. This is typically done by systematically applying informed judgments to the ranking process. A technical advisor who is familiar with the uncertainties and non-quantitative factors of the analysis should take part in the process to ensure that such issues are communicated, correctly interpreted, and incorporated in the rankings.

Cancer Risk Ranking

Ranking problem areas involves considering quantitative and non-quantitative factors, and determining their relative importance. As a result, the ranking process involves a great deal of judgment.

Quantitative Factors

- *Cancer Incidence*—In most regional and state comparative risk projects, the estimated number of annual excess cancer cases is the driving factor in the initial ranking of problem areas.
- *Individual Risk*—Differences in estimated individual lifetime risks are also important. In past projects, they have typically been considered after an initial ranking based on population risks.
- *Sensitive Subpopulations*—Environmental problems that pose relatively large risks to highly vulnerable or exposed populations deserve particular attention in the ranking process to ensure that decisions based on average risks do not underestimate inequitable risks to these groups.

Non-quantitative Factors

- *Severity of Health Effect*—Most comparative risk analyses have not distinguished between the severity of the different types of cancers. However, in situations where the cancers are not fatal, distinctions could be made and factored into the ranking process.
- *Omissions in the Analysis*—It may not be possible to analyze all aspects of every problem area, and it is likely that some problems will be more comprehensively analyzed than others. Therefore, it is important to identify omissions in the analysis and assess how completely the results characterize the risks. If a particular problem area is thought to have substantial omissions, then this should be highlighted in the ranking process.
- *Quality of the Data and Analysis*—Many factors can affect the quality of the data and the analysis and warrant consideration in the final ranking. The quality of toxicity and exposure data varies tremendously. For instance, the quality of medical or regulatory case-study data, ambient- or biological-monitoring data, animal-testing data, and epidemiological data are quite distinct from one another.

- *Uncertainty*—Omissions in the analysis and data-quality issues are components of uncertainty. In addition to these uncertainties, quantitative estimates of uncertainty related to estimated exposure concentrations and populations at risk should be factored into the ranking process. If such estimates cannot be made, then the expected direction of the potential bias should at least be communicated to decision makers.

Combining Quantitative and Non-quantitative Factors

There is a spectrum of possible approaches to combine the quantitative and non-quantitative factors of cancer risks, ranging from purely judgmental to rigorously quantitative, in order to arrive at an integrated risk ranking. The following discussion presents three options—one at either end of the spectrum and an intermediate approach that imposes some quantitative structure on the ranking process.

At the judgmental end of the spectrum, one option is to examine the available information—both quantitative risk estimates and non-quantitative factors—to arrive at a ranking through a consensus-building process among work-group members. While simplistic in concept, the effectiveness of this approach should not be underestimated. Developing the cancer risk ranking requires simultaneous consideration of many pieces of information, and this type of process may provide the flexibility needed.

The purely judgmental approach may not, however, provide the structure necessary to effectively and objectively rank the problem areas. The work group may prefer an intermediate approach that introduces more organization and objectivity to the ranking process. One way to achieve this structure is to first group the problem areas based on ranges of cancer incidence, such as those described in Table 2.2.7.

Table 2.2.7: Cancer-Risk Ranking Groupings

Group	Expected Annual Cancer Deaths
1	> 1,000
2	100 - 1,000
3	10 - 100
4	< 10

Alternative groupings can be made based on a combination of population and individual risks or on "natural" breaks in the data. The groupings can then be adjusted based on considerations of other factors, such as the size of sensitive subpopulations, uncertainties in the analyses, and individual cancer risks (if not incorporated as a factor in the initial grouping). For example, if abandoned hazardous waste sites fall into Group 4 of the scheme presented in Table 2.2.7 because the expected number of annual cancer deaths is less than 10, the work group may choose to elevate the problem area because the estimated individual cancer risk is high relative to other problem areas and because uncertainties in the exposure assessment indicate that more people are likely to be exposed in the future.

While this type of grouping process may serve as an intermediate step to establishing an ordinal ranking, the work group may choose to forego a ranking and characterize the relative cancer risks posed by problem areas simply in terms of the groups. The problem areas that will be most problematic will be those with quantitative risk estimates that extend into more than one group. In particular, the work group will need to discuss those areas that straddle group boundaries.

More quantitative approaches to establishing cancer risk rankings are also possible. Such approaches are characterized by a more rigorous integration of quantitative and non-quantitative risk information. One approach would be to translate the different risk metrics and non-quantitative information into a consistent numerical form using a scoring system that has built-in weights representing the importance of different factors in ranking problem areas. The scores for the different factors could then be added to obtain problem area scores that could be the basis for a rank ordering of problem areas. Computer programs, such as the Analytic Hierarchy Process, are available to aid this type of ranking process. These types of ranking tools are discussed in Section 2.1.

Non-cancer Risk Ranking

Establishing a ranking of problem areas according to non-cancer risks also involves considering quantitative and non-quantitative factors and determining their relative importance. Ranking non-cancer risks is somewhat more complicated than ranking cancer risks because of the diversity of non-cancer health effects and the difficulty in estimating the potential number of cases. As a result, the ranking process involves a great deal of judgment in combining information on different factors. In past comparative risk studies, severity of health effects, dose/RfD ratio, and number of people exposed have been the primary factors on which the initial non-cancer ranking was based.

Quantitative Factors

- *Magnitude of RfD Exceedance*—The magnitude of the RfD exceedance is typically used to characterize the risks associated with non-carcinogens and is expressed as the ratio of the dose to the RfD (IER). This is an important factor in ranking problem areas for non-carcinogenic risks because the greater the dose/RfD, the greater the probability of experiencing an adverse health effect.
- *Number of People Exposed*—The number of people exposed to non-carcinogens at concentrations exceeding the RfDs represents the population at risk of developing the associated health effect. Because this factor is typically used to indicate the potential population risk, it is critical in establishing rankings of non-carcinogenic risks.
- *Sensitive Subpopulations*—Problem areas posing risks to highly susceptible populations deserve particular attention in the ranking process to ensure that decisions based on general population exposures do not overshadow risks to specific groups as well.

Non-quantitative Factors

- *Severity of Health Effects*—The severity of health effects is particularly important in ranking problem areas according to their non-cancer risks, since non-cancer health effects vary widely in type and severity with some producing lethal effects and others more subtle physiological effects.

- *Omissions in the Analysis*—It may not be possible to analyze all aspects of every problem area, and it is likely that some will be more comprehensively analyzed than others. As a result, it is important to identify omissions in the analysis and assess the extent to which the results characterize the whole problem area.
- *Quality of the Data and Analysis*—Many factors can affect the quality of the data and the analysis, and warrant consideration in the final ranking. The quality of toxicity and exposure data varies tremendously. For instance, the quality of medical or regulatory case-study data, ambient- or biological-monitoring data, animal-testing data, and epidemiological data are quite distinct from one another.
- *Uncertainty*—Omissions in the analysis and data quality issues are components of uncertainty. In addition to these uncertainties, quantitative estimates of uncertainty related to estimated exposure concentrations and populations at risk should be factored into the ranking process. If such estimates cannot be made, then the expected direction of the potential bias should at least be communicated to decision makers.

Combining Quantitative and Non-quantitative Factors

The general options for developing a final non-cancer risk ranking are similar to those discussed for cancer risk ranking in that they can be seen as existing along a spectrum that ranges from purely judgmental to rigorously quantitative. The following discussion presents the three options identified for cancer and their application to non-cancer risk ranking.

The option at the judgmental end of the spectrum is to examine the available information—quantitative estimates of potency and populations exposed, and non-quantitative factors—and arrive at a ranking through a consensus-building process among work-group members. This approach may provide the level of flexibility that is needed. However, it may not provide the structure necessary to effectively and objectively rank problem areas. The work group may prefer an intermediate approach that introduces more organization and objectivity to the ranking process.

One way to achieve this structure is to first group the problem areas based on ranges of the number of people exposed to non-carcinogens at concentrations above their reference doses. Alternatively, groupings can be made based on natural breaks in the data or on a combination of population at risk, dose/RfD ratio, and severity of health effect. Separate groupings could be made for each of these factors and then combined into one overall grouping. The groupings could then be adjusted based on consideration of other non-quantitative factors, such as uncertainty or the quality of the underlying data. The problem areas that will be most difficult to place in one grouping or another will be those that overlap into the range of an adjacent grouping. Given the uncertainties surrounding estimates of risk for various problem areas, overlap among them is quite likely. However, despite this overlap, there should be large enough distinctions among groupings that those ranking them will be comfortable with the ranking results.

More quantitative approaches to establishing non-cancer risk rankings are also possible. Such approaches are characterized by a more rigorous integration of quantitative and non-quantitative risk information, and have been used for past comparative risk studies. One approach was used in *Unfinished Business* (EPA 1987) and has been used in many of the regional comparative risk studies. This approach involves the use of a scoring system (see Table 2.2.8) that translates information on population exposed, dose/RfD ratio, and severity of health effect into a consistent numerical form. This system uses a four-point scale for all three factors, in essence giving them equal weight in the overall score. Other approaches might weigh factors differently, depending on the work group's judgment of the relative importance of the different factors.

Table 2.2.8: Non-cancer Risk Ranking Groupings

Dose/RfD Score	Individual Exposure Ratio
1	< 10
2	10 - 100
3	100 - 1,000
4	> 1,000
Exposure Score	**Exposed Population**
1	< 1,000
2	1,000 - 100,000
3	100,000 - 10,000,000
4	> 10,000,000
Severity Score	**Endpoint Severity Index**
1	1 - 2
2	3 - 4
3	5 - 6
4	7

In a practical sense, each pollutant within a problem area would be scored, and the result for each pollutant would be consolidated for the problem area score. There are several approaches for doing this. One approach would be to select the chemical with the most severe health effect and use it to represent the problem area. In this case, the aggregate score for the chemical with the most severe effect would be the aggregate score for the entire problem area. Alternatively, the work group could use the pollutant with the highest aggregate score to represent the problem area. If either of these approaches is used, some problem areas are likely to be better represented than others, and this will need to be factored into an evaluation of uncertainty. A third alternative is to calculate an overall score that incorporates the scores for all pollutants analyzed by either averaging or adding the scores for individual pollutants. The problem with these approaches is that the results are largely dependent on the number of pollutants analyzed. Adding scores for different pollutants may underestimate the relative risks for some problem areas for which only a few substances were analyzed, and averaging scores may underestimate relative risks for problem areas that have one dominant pollutant but for which many less risky ones were also analyzed.

Regardless of how the scores are aggregated to obtain a total score for non-cancer health effects associated with each problem area, this approach allows problem areas to be ranked according to their scores. An uncertainty score could also be incorporated into this system that would adjust the aggregate score upward if there was a high degree of uncertainty associated with the assessment of the problem area. For example, scores of one, two, or three could be added for low, medium, and high levels of uncertainty. The factors to consider in evaluating the degree of uncertainty associated with the assessments include the quality and quantity of data used (e.g., animal toxicity data, epidemiological data, ambient- and biological-monitoring data, and medical or regulatory case-study data), the number of chemicals analyzed, and the degree of extrapolation performed. Uncertainties in the more quantitative factors could be considered in assigning scores for potency, exposure, and severity.

Step 6: Combine Cancer and Non-cancer Risks

From the standpoint of providing inputs to the risk management phase of the effort, producing a combined health risk ranking incorporating cancer and non-cancer effects can be useful. A combined health ranking is also more consistent with the outcomes of the quality-of-life and ecological analyses and allows for more direct comparisons of problem areas for planning, budgeting, and resource allocation purposes.

The process for combining cancer and non-cancer health effects can be non-quantitative or semi-quantitative. A non-quantitative approach relies heavily on the judgment of the work group to interpret the significance of the various quantitative and non-quantitative factors. The outcome of this process might be an ordinal ranking or the assignment of problem areas to categories representing various levels of risk arrived at through group consensus.

A useful tool to aid this process would be to array the information most critical to the ranking decisions in a matrix that combines cancer and non-cancer effects. An example of such a matrix is shown in Table 2.2.9 This table presents a partial representation for illustrative purposes; a complete summary table would include risk estimates for all problem areas.

The most important thing about this table is that it groups cancer and non-cancer health effects into three separate categories of relative risk: catastrophic, serious, and adverse. Most displays of health effects separate cancer from non-cancer health effects. This table presumes that the issue of greatest importance is the severity of the health effect rather than distinguishing between cancer and non-cancer cases.

This matrix combines information on the number of people at risk to cancer and non-cancer effects of varying severity for three problem areas. This allows for direct and meaningful comparison of the factors critical to ranking. The number of people at risk from cancer is actually an estimate of the incidence of disease, whereas the estimates for non-cancer health effects represents the number of people exposed to potentially harmful conditions (i.e., with a dose/RfD ratio of greater than one). In cases where incidence data are available for non-cancer effects, the metrics may be more comparable. Once the work group establishes an initial ranking, other factors such as individual risks, the magnitude of RfD exceedances, and uncertainty, can be considered in adjusting the ranking.

Table 2.2.9:
Summary Matrix of Cancer and Non-cancer Effects

Problem Area	Number of People at Risk From Cancer and Non-cancer Health Effects		
	Catastrophic	Serious	Adverse
Air Toxics	12.5*		
	5,000	250,000	800,000
Drinking Water	4*		
	2,000	50,000	250,000
Hazardous Waste	1.2*		
	100	5,000	10,000

Number of potential cancer cases are noted by an asterisk (*); all other numbers represent the estimated number of non-cancer health effects with dose/RfD ratios > one.

Although this judgmental approach offers a great deal of flexibility, it may not provide the structure necessary to objectively rank the combined human health risks of different problem areas. The work group may prefer a more organized, semi-quantitative approach. Table 2.2.10 illustrates how this could be accomplished, using the three categories of relative risk displayed in Table 2.2.10 (i.e., catastrophic, serious, and adverse). It would seem reasonable to assume that there would be a greater level of concern over catastrophic health effects than either serious and adverse effects, and greater concern over serious effects than adverse effects. Theoretically, different weights could be attached to the different categories to reflect the different levels of concern with the more severe health effects.

The table presents hypothetical cancer and non-cancer rankings for six problem areas and an overall human health rating, which is simply the aggregation of the health effect category rankings. In this example, no explicit weights have been attached to the different categories of effect, although this could easily be done. If the work group wanted to place more or less importance on the different categories, it could make adjustments by weighting them accordingly.

The drawback of this type of approach is that it relies completely on the initial rankings and does not reconsider the relevant factors in the context of a broader human health ranking. An alternative semi-quantitative approach to combined rankings that explicitly incorporates consideration of these factors would be to develop a more elaborate scoring scheme, such as a modification of that used in *Unfinished Business* (EPA 1987) to rank non-cancer effects (see discussion of non-cancer risk ranking). The modifications could include incorporating criteria for average individual cancer risk, population cancer risk, and severity of cancer effect to establish respective potency, exposure, and severity scores for cancer effects. Great care must be taken in developing such a scoring scheme to ensure that the judgments implicit in the relative scores are consistent with the work group's understandings.

Table 2.2.10
Combining Cancer and Non-cancer Effects

Problem Area	Catastrophic Ranking	Serious Ranking	Adverse Ranking	Overall Rating
Air toxics	High	High	High	High
Drinking water	Low	Low	Medium	Medium/Low
Pesticides	Medium	Medium/ High	Medium/ High	Medium/ High
Indoor air	Medium	Medium	Medium	Medium
Surface water	Low	Low	Low	Low
Hazardous waste	Low	Low	Low	Low

The options presented here for combining cancer and non-cancer risks into an overall human health ranking are only examples of general approaches that can be considered. Each approach involves some effort to develop and implement, but the effort is well worth it since it is crucial that project participants and the general public understand the approach and find it reasonable and reflective of their values. Factors that the work group might want to consider in developing an appropriate approach include agreeing on the objective of the effort, the quality and precision of the analytic results, the expertise of the ranking group, and the time and resources available. It is important to consider these factors in the planning phases of the project so that data can be developed and presented in a way that is consistent with and supports the approach used in ranking problem areas.

REFERENCES

Casarett, Louis J., and John Doull. *Casarett and Doull's Toxicology.* Edited by John Doull, Curtis Klaassen, and Mary Ambdur. New York: Macmillan Publishing Co., Inc. 1980.

Finkel, Adam M. *Confronting Uncertainty in Risk Management.* Center for Risk Management, Resources for the Future. Washington, D.C. January 1990.

National Academy of Sciences. *Risk Assessment in the Federal Government: Managing the Process.* Washington, D.C. 1983.

U.S. Environmental Protection Agency (U.S. EPA). Office of Health and Environmental Assessment. Environmental Criteria and Assessment Office. *General Quantitative Risk Assessment Guidelines for Non-cancer Health Effects.* Second External Review Draft. Cincinnati, OH. February 1991.

U.S. EPA. Science Advisory Board. *Report of the Human Health Subcommittee: Relative Risk Reduction Project,* Appendix B. Washington, D.C. September 1990.

U.S. EPA. *Ambient Particulate Matter and Ozone Benefit Analysis for Denver.* Prepared by RCG/Hagler, Bailly, Inc. Washington, D.C. 1988a.

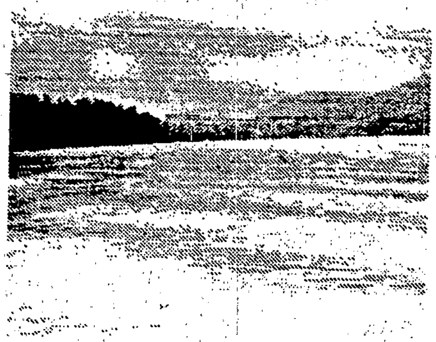
U.S. EPA. Office of Research and Development. Environmental Criteria and Assessment Office. *Integrated Risk Information System.* Background Document 2: "EPA Approach for Assessing the Risks Associated with Chronic Exposures to Carcinogens." Cincinnati, OH. February 1988b.

U.S. EPA. Office of Policy, Planning and Evaluation. Office of Policy Analysis. *Unfinished Business: A Comparative Assessment of Environmental Problems,* Appendix II. Washington, D.C. February 1987.

U.S. EPA. "Guidelines for Carcinogen Risk Assessment." *Federal Register,* vol. 51, no. 185 (9/24/86). Washington, D.C.

U.S. EPA. *Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments.* Prepared by GCA Corporation. Washington, D.C. August 1985.

U.S. EPA. Office of Health and Environmental Assessment. *Handbook for Performing Exposure Assessment.* Washington, D.C. 1983.



2.3 Comparing and Assessing Ecological Risks

TABLES

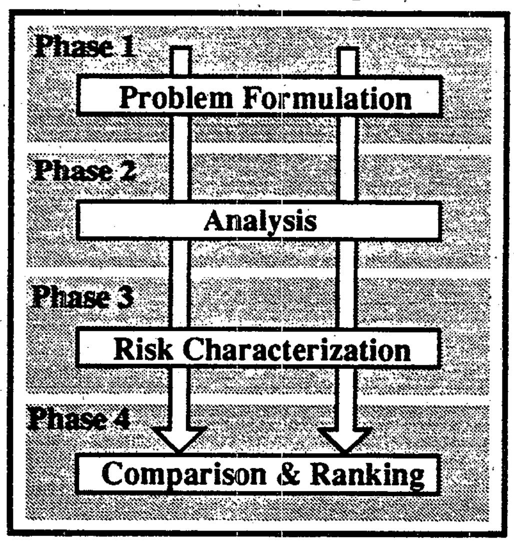
EXHIBITS

A comparative ecological risk analysis is a process of identifying, analyzing, evaluating, and ranking the effects of manmade "stressors" on ecological "receptors." A stressor is any chemical agent or physical activity that can harm an ecological receptor. An ecological receptor[1] can be an individual of a single species, a population of species, a community of interacting species, or the functional or structural integrity of an entire ecosystem. Risk does not exist unless a stressor comes into contact or co-occurs with an ecological receptor.

A comparative ecological risk analysis applies the principles of risk analysis to available data, supplemented by best professional judgment, to rank the relative risks of significant environmental "problem areas." Problem areas are evaluated and ranked in terms of a set of criteria that reflect the environmental values that society is most concerned about, such as the loss of biodiversity or whether the damage is temporary or irreversible.

As presented in Exhibit 2.3.1, a comparative ecological risk analysis involves four phases. Each of these phases is discussed in summary below and in detail further on. Because the process is iterative, it may be necessary and advisable to revisit some initial decisions in later phases to ensure that they are still appropriate.

Exhibit 2.3.1:
Four Phases of a Comparative Ecological Risk Assessment



Phase 1: *Problem Formulation.* The first phase of a comparative ecological risk analysis is a systematic planning process that includes reviewing the list of environmental problem areas, partitioning the project area (e.g., a state) into a number of different ecological or geographic areas, and selecting a set of criteria to evaluate ecological risks and rank the problem areas. In addition, a preliminary examination of data needs and constraints may be necessary.

Phase 2: *Analysis.* In the second phase of an analysis, the goal is to establish a causal link between the problem areas and their ecological effects. Therefore, each problem area is broken down into a set of the most important stressors. The fate and transport of each stressor is then tracked through the environment to determine likely ecological effects. This requires knowledge about the toxicity of chemical stressors and the presence of physical stressors, the exposure or co-occurrence of ecological receptors to stressors, and the response of ecological receptors to stressors. Where data are lacking or inadequate, professional judgment and consensus building are needed to supplement gaps in data, sources of uncertainty, and a lack of knowledge about complex ecological processes and interactions.

Phase 3: *Risk Characterization.* The third phase of a comparative ecological risk analysis involves using the analyses to characterize the risks posed to the environment by different problem areas. Risks are characterized in terms of a set of common evaluative criteria. These criteria may include factors such as the area, severity, and reversibility of impacts. Values or weights can be assigned to each criterion using numerical scales or short narrative descriptors. Risk characterization also includes a summary of the assumptions and scientific uncertainties embedded in the analysis and their anticipated implications.

Phase 4: *Comparison and Ranking.* The final phase of a comparative ecological risk analysis involves comparing the ecological risks posed by different problem areas and ranking them into several broad categories. This is accomplished by considering ecological risks for each problem area in terms of the evaluative criteria. Professional judgment supplements gaps in data or knowledge, but the level of precision required is only as great as that needed to make rough relative comparisons, rather than absolute estimates, of risk. Problem areas are then ranked using a mixture of available data and best professional judgment through a consensus-building process.

PHASE 1: PROBLEM FORMULATION

The problem formulation phase of a comparative ecological risk analysis consists of a systematic planning process to establish the goals, breadth, and focus of the analysis. Three major tasks are performed in this phase. First, the problem area list is reviewed to identify problem areas that do not pose any ecological risks, such as indoor radon. These problems do not need to be analyzed from an ecological perspective. Second, the area of the analysis, such as a state or a region of the country, should be partitioned into different ecological or geographic areas. Third, the criteria used to evaluate and rank problem areas should be selected and defined.

Task 1: Review the List of Problem Areas and Definitions

Most problem areas will generally be applicable to all three analytical components (i.e., the human health, ecological, and quality-of-life analyses) of a comparative risk project. However, a few problem areas may not have an ecological component and do not need to be analyzed by the ecological work group. For example, radon does not pose any ecological risks, but does pose both human health and quality-of-life risks. Conversely, other problems that cause ecological impacts may not be on an initial list of problem areas and should be added. The most prominent example of this has involved the physical alteration and degradation of terrestrial and aquatic habitats, such as urban sprawl or filling wetlands.

All problem areas should be clearly defined in terms of which sources, stressors, and exposure pathways are included and excluded in the definitions. Since they will be conducting the analysis, the ecological work group members should be consulted extensively about definitional issues or any other issues affecting the ecological analysis. Work group members may want to review Section 2.1 on selection criteria for developing a problem-area list.

Colorado conducted a comparative risk project in 1988-90 using a problem-area list and analytic design that reflects its own unique natural environment and public concerns (Colorado 1990). The 31 problem areas in Colorado's list were separated into four categories: air, land, water, and natural resources. This list was intentionally constructed with some overlap between problem areas, and the project acknowledged the possibility of some double counting of risks.

A noteworthy aspect of Colorado's project is the natural resources problem-area list and analytic approach. Rather than using the effects of pollution as the basis for analyzing and ranking problem areas, the natural resources work group focused on the ecological value, vulnerability, and economic value of different ecosystems. The 10 problem areas in the natural resources category are listed in Exhibit 2.3.2.

Exhibit 2.3.2:
Portions of Two State Problem-Area Lists

Colorado's Natural Resources List	Unique Michigan Problem Areas
• Wetlands and Riparian Areas	• Absence of Land-Use Planning
• Threatened and Endangered Species Habitats	• Biodiversity/Habitat Modification
• Resources of Special Interest	• Lack of Environmental Awareness
• Critical Wildlife Habitats	• Contaminated Surface-Water Sediments
• Aquatic Habitats	• Electromagnetic Field Effects
• Recreation Opportunities	• Energy Production and Consumption
• Urban Environments	• Alteration of Surface-Water and Ground-Water Hydrology
• Plains Land	
• Forests	
• Open Space	

The Michigan project developed a list of 23 problem areas (Michigan 1992). Some of the more unusual and original problem areas are also below in Exhibit 2.3.2. Unlike Colorado, each of the three working committees (an agency committee, a citizens' committee, and a scientists' committee) evaluated and ranked all 23 problem areas.

Task 2: Partition the Study Area Into Geographic or Ecological Areas

The study area (e.g., a state or region of the country) of a comparative risk project should be partitioned into a manageable number of ecosystem types or geographic areas. Different ecosystems vary in their vulnerability and resilience to stressors, while the same type of ecosystem in a different geographic location may be more at risk due to a very different stress regime. If the study area is partitioned according to ecosystem type, then different ecosystems, such as wetlands or pine forests, would be analyzed regardless of their location throughout the state. Conversely, the study area can be partitioned into separate and distinct geographic areas, such as particular rivers, valleys, or mountain ranges.

Partitioning the study area into a number of ecological or geographic areas also makes it possible to evaluate ecological risks in a cross-cutting fashion. First, the risks due to a particular environmental problem can be summed across all ecological or geographic areas in the study area to determine the total risk posed by that problem area. Not only will managers know which problems pose the greatest risks to the environment, they will also know where the most severe risks occur and can target response activities in those areas. Conversely, the total risk posed by all the problem areas within a given ecological or geographic area can be summed up to determine which ecosystems or geographic areas are at greatest risk overall. This information allows environmental managers to integrate cross-media response activities that address multiple threats simultaneously in those ecosystems at greatest risk.

How the project area is partitioned is important because it affects many aspects of the analysis, such as the number of analyses that are performed, the amount and type of data that must be collected and analyzed, and the degree of resolution and geographic targeting that can be achieved as a result of conducting the analysis. Therefore, selecting the appropriate ecological approach depends on the purpose for conducting the analysis, the availability and quality of data, the size and natural variability of the project area, and the ease and effectiveness of communicating the analytic approach and results to senior managers, political leaders, and the public.

By Geographic Areas

Several comparative risk projects have partitioned their state or region into specific geographic areas, such as particular bays, river valleys, grasslands, or mountain ranges. This approach is used for a number of reasons. First, since the damages caused by stressors are spatial in nature, it makes sense to analyze the likelihood of adverse effects geographically, rather than by the ecological type of the receptor. For example, mixed conifer forests in southern California are likely to be exposed to much higher levels of air pollution than the same type of forests in northern California. Attempting to describe the combined damages to all mixed conifer forests in California as a single value is likely to be unsatisfactory.

Another important advantage of dividing the study area into specific geographic areas is that it may be easier to communicate with and build support among the general public about the results of a comparative risk project. For instance, it may be more difficult to communicate to the public the risks of pesticide use in bottomland hardwood forests or tall grass prairies than to rally public support around the risks posed to a specific area (e.g., the "Save the Bay" campaign in the Chesapeake Bay area). Exhibit 2.3.3 illustrates the cross-cutting approach mentioned above that was used in the EPA Region VI comparative risk project in 1990 (EPA 1990a).

Exhibit 2.3.3:
Calculating Risk Using the EPA Region VI Cross-Cutting Approach

EPA Region 6 Ecoregions → Problem Areas	AZ/NM Plateau	AZ/NM Mountains	Southern Rockies	Arkansas Valley, AR/OK	Flint Hills, OK	Texas Blackland Prairies	Southern Coastal Plains, LA	Miss. Alluvial Plains, AR/LA	Ozark Highlands, AR/OK	Total Risks by Problem Area
Non-point Discharges to Surface Waters										
Physical Degradation of Water and Wetlands										
Municipal (POTW) Discharges to Surface Waters										
Active Hazardous Waste Sites (RCRA)										
Abandoned Hazardous Waste Sites (Superfund)										
Application of Pesticides										
Ozone and Carbon Monoxide										
Physical Degradation of Terrestrial Habitats										
Total Risks by Ecoregion										

Ecoregions are geographic areas of relative ecological homogeneity in terms of the relationships between organisms and their environments. They are distinguished by land use, topography, potential natural vegetation, and soil type. EPA Region VI chose to use ecoregions, as opposed to ecosystems, as the unit of analysis for several reasons. First, all 24 ecoregions located within the five-state area of Region VI have been electronically mapped or "digitized." In fact, all 76 ecoregions located within the 48 U.S. continental states have been digitized. Second, by digitizing ecoregions into a geographic information system (GIS), it is possible to simultaneously analyze multiple layers of other digitized data sets and graphically display them on an ecoregion-by-ecoregion basis. For instance, Region VI was able to analyze and display the spatial relationship of ground-water resources to underground storage tanks, roads, and waste sites. Finally, the 24 ecoregions provided a level of resolution that was sufficient, yet manageable for the region's purposes.

However, not every comparative ecological risk analysis should evaluate risks at the ecoregion level. For instance, in states like Georgia or Nevada, where one ecoregion covers over 75 percent of the entire land area, this approach may not provide an adequate level of resolution. In addition, GIS technology is very resource-intensive and expensive and may not be critical or necessary to the success of every project.

By Ecosystem Type

Many state and EPA comparative risk projects to date have classified ecological areas by type. The distinction among ecological types can range from very simple schemes, as demonstrated by the Vermont comparative risk project, to more complex approaches, such as that used in Hawaii's project, which specified over two dozen ecosystem types (Vermont 1991; Hawaii 1992). These state examples are shown in Exhibit 2.3.4.

Exhibit 2.3.4:
Ecosystem Classification Schemes Used in Two State Projects

Vermont	Hawaii
• Terrestrial ecosystems	• Reefs (both barrier and fringing)
• Aquatic ecosystems	• Coastal waters, bays, and beaches
• Wetlands	• Wetlands, streams, and estuaries
• Rare ecosystems	• Lowland tropical moist forests
	• Lowland and montane dry forests
	• Lava tubes and caves
	• Grasslands
	• Arid lands
	• Alpine deserts

In Vermont, the most important stressors associated with each problem area were analyzed in terms of their ecological effects on four types of ecosystems. Ecological effects were measured in terms of the size of the area affected, disruptions to the function and structure of whole natural communities rather than individual species, and recovery time for the ecosystem to return to a natural state once the stressor was removed.

The Hawaii Environmental Risk Reduction project originally partitioned the Hawaiian islands (excluding urban and agricultural areas) into 29 different ecosystem types. To make the analysis more manageable, this number was later lowered to 18 by combining similar ecosystem types. Furthermore, every "occurrence" of each ecosystem type was individually assessed because of the different stress regimes experienced by the same ecosystem type in different locations on the islands. For instance, the risks to fringing reefs on opposite sides of an island or on different islands can vary tremendously because of their exposure to different kinds and magnitudes of stress. Project participants believe that these are important distinctions that justify the higher costs and effort required to collect the information because environmental managers can then target activities to address threats to specific ecosystems at the greatest risk.

Exhibit 2.3.5 below depicts two different approaches used at the federal level to partition the natural landscape according to ecosystem type. On the left is the approach used by the ecological work group of EPA's *Unfinished Business* project (EPA 1987); the approach on the right is the approach used by EPA's Environmental Monitoring and Analysis Program (EMAP).

Exhibit 2.3.5:
Federal Approaches to Classifying Ecosystems

Ecosystems Defined by EPA's National Comparative Risk Project	Resource Classes Defined by EPA's EMAP Office
Freshwater Ecosystems Buffered lakes Unbuffered lakes Buffered streams Unbuffered streams *Marine and Estuarine Ecosystems* Coastal ecosystems Open ocean ecosystems Estuaries *Wetland Ecosystems* Buffered freshwater isolated wetlands Unbuffered freshwater isolated wetlands Freshwater flowing wetlands Saltwater wetlands *Terrestrial Ecosystems* Coniferous forests Deciduous forests Grassland ecosystems Desert and semiarid ecosystems Alpine and tundra ecosystems	*Inland Surface Waters* Lakes Streams *Near Coastal Waters* Large, continuously distributed estuaries Large, continuously distributed tidal rivers Small, discretely distributed estuaries, bays, inlets, tidal creeks, and rivers *Wetlands* Lacustrine Palustrine Riverine *Forests* 22 forest types *Arid Lands* Grasslands, Savanna Chaparral, Shrublands Woodlands, Tundra Riparian *Agroecosystems* Field, vegetable, and forage crops Fruit and nut crops Managed pasture and non-confined animal operations Confined animal-feeding operations

Task 3: Select Evaluative Criteria

The information upon which ranking decisions are based can simultaneously be overwhelming and inadequate. This can lead to a feeling of comparing apples and oranges. However, a set of evaluative criteria can "translate" the risk characterizations for different problem areas into a common language so that decision makers can compare and rank them. Evaluative criteria also help in limiting the scope of data collection and analysis efforts to information that is pertinent to the types of decisions that will ultimately need to be made.

To be useful in evaluating and comparing problem areas, criteria should:

- Be explicitly defined to be mutually exclusive. This prevents double counting certain aspects of the impacts, such as the "severity" and "reversibility" of effects.
- Be common to all problem areas, which vary considerably, to facilitate consistent analysis across problem areas.
- Vary from one problem area to the next, even though they are common to all problem areas, such as the area or severity of impact.
- Be measurable and, if possible, quantifiable. Any subjective judgments used to evaluate problem areas should be peer reviewed and documented for the benefit of any future reference or outside review.

Classifying or "scoring" ecological effects for most evaluative criteria often involves using some professional judgment. Thus, the risk ranking will reflect the experience and knowledge of the individuals working on the project. Depending upon the resources available and the objectives of the project, the ecological analysis can range from simple non-quantitative statements based upon the knowledge of the project participants to more data-intensive approaches that quantify multiple aspects of the effects. For example, trend analyses might simply involve the work group agreeing that the impacts of a given problem area are increasing, remaining stable, or decreasing. It may also use a more quantitative approach of modeling various economic, technological, and demographic trends. However, the ecological analysis does not have to be a labor- and data-intensive undertaking. In fact, the analysis should be no more detailed and resource-intensive than is necessary to rank problem areas relative to one another and identify the ecosystems or geographic areas at greatest risk.

During the past several years, a number of evaluative criteria have consistently been used in regional and state comparative ecological risk projects. Some of these criteria are described below.

Area of Impact

The area of potential impact in comparative risk projects is based on the extent of the *effect*, rather than the area of overlap between stressors and ecological receptors. This is because the effects of a given stressor on a receptor can extend far beyond the immediate area of their co-occurrence. For instance, the effects of eliminating a critical habitat for migrating waterfowl or anadromous fish can extend far beyond that area to the entire migratory flyway or aquatic life-cycle habitat of that species.

The first step, which can be difficult, is to estimate the proportion of impacted area within each ecosystem or geographic area. Then it is a simple matter to sum these estimates across ecosystems or geographic areas to determine the entire area affected within the study area. This step differs among problem areas. For example, in the case of air pollutants, the entire ecosystem may be assumed to be affected. However, the most severe impacts may be limited to urban areas, with less severe effects experienced in rural parts of the ecosystem. The area of impact for waste sites has been estimated by using an average estimate for each site and then multiplying that by the number of sites within the ecosystem. Information on the number of stream miles or coastline affected or the number and location of violations of water permits may be used to estimate the area of impact in aquatic environments.

Severity of Impact

Effects from both physical and chemical stressors can be analyzed and evaluated in terms of their "severity" on ecosystems or geological areas. This is a function of the toxicity of a chemical stressor, the exposure to the stressor, and the vulnerability of the ecosystem or geographic area. For physical stressors, the degree or kind of impact is estimated and characterized, rather than the stressor's toxicity. For instance, the building of a road through a migration corridor is likely to cause habitat loss and fragmentation and may disrupt reproductive activities.

Defining terms carefully and clearly is probably most critical for the severity criterion. It is important to keep criterion mutually exclusive in order to avoid double-counting effects under two separate criteria. By its very nature, the concept of severity tends to encompass other criteria, such as vulnerability or reversibility. For instance, when evaluating the severity of a chemical stressor on an ecosystem, it is difficult to separate the toxicity of the stressor from the ecosystem's vulnerability to it. Similarly, the severity of an effect can easily be stated in terms of its reversibility. For example, if a problem area is ranked high in terms of severity because it causes "permanent or irreversible damage to the ecosystem," then double counting of effects is occurring if there is a separate "reversibility" criterion. It is preferable to retain the distinction of reversibility as a separate criterion from severity in order to be able to distinguish one stressor that causes severe and long-term effects from another stressor that may be equally severe but has short-lived effects.

Reversibility of Impact

The reversibility criterion is used to account for the resilience of different ecosystems and the persistence of physical or chemical stressors. It is an estimate of the time required for an ecosystem to regain its normal structural and functional properties after the stress has ceased. Reversibility can be measured in terms of very short time periods (e.g., days, weeks, or months) to much longer time periods (e.g., years, decades, or irreversible effects). Whatever time periods are used should be sufficiently broad to indicate very large differences in the reversibility of impacts. For instance, if a five-point interval scale is used, then a value of one might indicate the ecosystem's return to normalcy in less than one year, whereas a score of five might indicate an irreversible effect. Intermediate scores would be assigned to periods ranging from several years to decades to centuries.

There is an important distinction to keep in mind between the reversibility of impacts and the vulnerability of different ecosystems, which is sometimes confusing. While the reversibility of an impact is clearly a component of an ecosystem's vulnerability, the two terms can be distinguished in terms of the timing of the stress. The vulnerability of an ecosystem to stress indicates the ecosystem's response to a stressor, whereas the reversibility of an effect indicates the ecosystem's ability to bounce back from a stress following the cessation of that stress. These are simply different ways of analyzing the same phenomenon. However, it is useful to maintain this distinction.

Uncertainty

The degree of uncertainty associated with each of the evaluative criteria should be noted to decision makers. The uncertainty surrounding estimates may be attributed to a number of sources: lack of data and knowledge about stress-response relationships, inferential judgments of community- or ecosystem-level effects based on data at lower biological levels of organization, extrapolating information from a small sample size or another section of the country where conditions might differ, or interpolating information from regional or national studies.

Uncertainty can also be used as a qualifier rather than as an explicit evaluative criterion. Options include using uncertainty to increase the risk estimate (i.e., higher uncertainty would result in a higher risk estimate), to decrease the risk estimate (i.e., higher uncertainty would result in a lower risk estimate), or as a communication tool (i.e., the level of uncertainty would not affect the risk estimate but would be communicated to decision makers). Uncertainty can be used as an indication of the "cost" of being wrong; in this case, uncertainty surrounding the catastrophic potential of a problem area (e.g., global warming) would raise the risk estimate. From a practical standpoint, high uncertainty can be used to identify areas where new research and data collection efforts are particularly important versus other problem areas where uncertainty is minimal and response activities can be implemented immediately. Moreover, sensitivity analyses can be very valuable in bounding uncertainty estimates.

"Value" of Ecosystems

This criterion is used to represent the different values attached to different ecosystems due to their scarcity, ecological value, uniqueness, human valuation, or any number of other factors creating value. The advantage of this criterion is that it can highlight the importance of certain ecosystems in order to focus attention on the problem areas affecting them. Conversely, not including an ecosystem's value or importance in a ranking process implies that all ecosystems are equally valuable.

To illustrate this point, a project's participants may decide that the ranking of a problem area, such as outdoor air pollution affecting an important national park, is too low based solely upon the area and severity of impact and its reversibility. It may be that due to other "values" the park provides to man and nature, the problem area should be ranked higher. Or decision makers might believe that ranking a 10 percent loss of the few remaining wetlands in a state should be higher than a 10 percent loss of rangeland acreage because of the scarcity of wetlands and the critical habitat it provides to a complex community of animal and plant species, even though the area, severity, and reversibility of impact are roughly equal to the rangeland loss. A value criterion can provide a way to reflect this difference in the relative value of ecosystems.

Only a small minority of projects to date have added a "value" criterion to their evaluative criteria. Some project participants believe that the value of ecological areas to people, in terms of recreational, spiritual, or aesthetic benefits, should be addressed in the quality-of-life analysis of a comparative risk project. Other participants think that all ecosystems are equally important and valuable and that these evaluations are too subjective to be scientifically credible. The decision to include value as an evaluative criterion is a choice that must be made on a project-by-project basis.

Phase 2: Analysis

The analysis phase of a comparative ecological risk analysis consists of three main tasks: identifying the physical or chemical stressors associated with each problem area, estimating the exposure or co-occurrence of these stressors with ecological receptors of concern, and characterizing the resulting ecological effects. Ideally, it would be possible to establish a causal relationship between stressors and their ecological effects. However, this is rarely achieved because of gaps in knowledge or data, uncertainties, or information that must be interpolated from larger studies (e.g., national studies) or extrapolated from smaller studies (e.g., site-specific studies). Often, the ecological effects of interest in a comparative ecological risk analysis are at higher levels of biological organization, such as the community and ecosystem levels, than the available information. These effects are often based on studies at lower levels of biological organization, such as field or laboratory studies of a single species population. This introduces uncertainty and requires applying professional judgment carefully.

Task 1: Identify Stressors

A "stressor" is defined as any physical or chemical agent that can induce an adverse ecological effect. Examples of physical stressors include draining wetlands or channeling rivers. The ecological effects they might cause include the loss of natural resources, filtering and detoxification functions, and wildlife habitat. Chemical stressors include organic and inorganic substances such as lead, asbestos, heavy metals, and volatile organic compounds. They can affect any level of biological organization from an individual of a species to an entire ecosystem or landscape.

Stressors should be identified for every problem area analyzed. For some problem areas, the stressors are obvious, such as environmental lead and asbestos. In these cases, the risk associated with each problem area is determined by a single stressor. However, for many problem areas with multiple stressors it is not practical to conduct an ecological analysis for each one. In these cases, it is necessary to select a manageable number of the most important stressors and assess their cumulative impact. There are also problem areas where the secondary stressors are very important to analyze, such as stratospheric ozone depletion caused by chlorofluorocarbons (CFCs) which can result in increased exposure to ultraviolet radiation. An example of a secondary physical stressor is removal of riparian (streamside) vegetation that not only alters habitat structure and favors shade-intolerant tree species directly, but also can have secondary impacts such as increased siltation of stream bottoms and higher water temperatures.

Analysts knowledgeable about a particular environmental problem should be able to use their best professional judgment and experience to identify the most important stressors for each problem area in terms of its prevalence, persistence, and/or toxicity. The group of stressors selected for each problem area should be representative. This will ensure that the analysis will encompass the most serious risks, rather than risks from inconsequential stressors. Data availability and quality may also be a consideration in selecting stressors.

Table 2.3.1 shows some of the more commonly used stressors and likely sources for the ecological problem-area list that EPA has used for a number of regional and state projects. This table merely suggests a number of candidate stressors and is not meant to be comprehensive or definitive. Each project must sort through its own unique set of stressors to identify the most important ones.

Task 2: Estimate Exposures/Co-occurrence

To characterize ecological risk, there must be a stressor present with the ability to cause an adverse effect to an ecological receptor. The magnitude and length of exposure is important in calculating risk, but the timing of the exposure is also important. For instance, if the stressor is episodic (e.g., pesticide use), then different species and life stages may be affected. Likewise, the location of contact can also be critical to the magnitude of stress experienced by receptors, such as important habitats or breeding areas along a transcontinental flyway or a spawning area for anadromous fish species. Stressors are also affected by the environment which in turn can modify the exposure of ecological receptors. For instance, siltation and sedimentation depend not only on sediment volume, but also on water flow and the stream's physical characteristics. Similarly, chemical stressors can be modified through biotransformation by microbial communities or other environmental-fate processes, such as photolysis and hydrolysis.

The most common way of estimating exposure is to analyze measured concentrations or amounts of a stressor in terms of assumptions about its co-occurrence, contact, or uptake by ecological receptors most likely to be affected by it. For example, the exposure of aquatic organisms to chemical stressors is often expressed as the stressor's concentration in the aquatic environment; the aquatic organisms (receptors) are assumed to come in contact with the stressor. In the case of physical stressors, such as physical alteration of communities and ecosystems, exposure by ecological organisms that normally use the habitat is assumed and is expressed in terms of the area of co-occurrence.

Table 2.3.1:
Ecological Problem Areas, Stressors, and Sources

Problem Areas	Stressors	Sources
Industrial Waste-Water Discharges	Total suspended solids, biological oxygen demand (BOD), toxic organics and inorganics, pthalates and phenols, and thermal pollution	Metal finishing, pulp and paper processing, and iron and steel production (all NPDES permitted sites)
Municipal Waste-Water Discharges	Industrial waste-water discharges, plus ammonia, chlorination products, nutrients	Discharges from publicly and privately owned water treatment plants, and sewer overflows
Aggregated Drinking Water	No significant ecological risks	Not applicable
Non-point Source Discharges	Dirt and debris, toxic substances, leachate, stormwater and urban/agricultural runoff	Runoff from agricultural, urban, silviculture, industrial, and disturbed lands
Physical Degradation of Water/Wetland Habitats	Physical changes to water-flow quantity and patterns, and impacts to aquatic habitats	Channelization, levees, irrigation and other withdrawals, flood control, and urban development
Aggregated Ground Water	Nutrients, toxic inorganics and organics, salts, oil and petroleum products, and microbes	Waste sites and landfills, UST's and UIC's, road salts, leachate from septic systems, and runoff
Underground and Surface Storage Tanks	Releases of oil and non-petroleum products, such as motor fuels, heating oil, solvents, and toxic organic lubricants	Farm fuel tanks and grain silos, home fuel tanks, gasoline stations, and other storage
Active Hazardous Waste Sites (RCRA)	TCE/TCA, toluene, and toxic organics, such as heavy metals and PCBs	Open and closed landfills, surface impoundments, storage tanks, and waste from incinerators
AbandonedHazardous Waste Sites (Superfund)	Similar pollutants and mixtures to RCRA sites, plus radiation from "mixed waste"	Any abandoned site that is a candidate or listed NPL site, or state priority list site
Municipal Solid Waste Sites	Nutrients, BOD, microbes, toxic chemicals; air stressors include air toxics and particulate matter	Open and closed municipal landfills, sludge and refuse incinerators, and surface impoundments
Industrial Solid Waste Sites	Similar stressors to municipal solid waste sites, but the concentrations, volumes, and mixtures differ markedly	Industrial waste sites, open and closed industrial landfills, surface impoundments, and incinerators
Accidental Chemical Releases	Stressors released during transport or while stored include petroleum products, acids, and other toxic chemicals	Explosions at industrial plants, and releases during air, land, or sea transport
Pesticides	All types of herbicides, insecticides, fungicides, nematicides, and rodenticides	Agricultural, suburban, and urban application, runoff, and oversprays; food-chain impacts
Physical Degradation of Terrestrial Ecosystems and Habitats	Physical alteration or destruction of natural terrestrial ecosystems, habitat fragmentation, migration path blockage, and litter	Urban/suburban sprawl, conversion to other uses, highway construction, and building resorts
Environmental Lead	Airborne lead and lead deposition in soil and surface waters	Leaded gasoline, landfills, surface impoundments, other contaminated sites; food-chain impacts
Noise Pollution	No significant ecological risks	Not applicable

Table 2.3.1 (continued):
Ecological Problem Areas, Stressors, and Sources

Problem Areas	Stressors	Sources
Sulfur Oxides and Nitrogen Oxides	Acid deposition, which results from the chemical transformation of sulfur and nitrogen oxides	Wide variety of industrial, commercial, and residential fuel, and related combustion sources
Ozone and Carbon Monoxide	Ozone and carbon monoxide	Both mobile (e.g., autos) and stationary sources similar to those for sulfur and nitrogen oxides
Particulate Matter	Fine particulates (PM-10) and total suspended particulates	Similar to those for sulfur/nitrogen oxides plus strip or open mines in some locations
Toxic Air Pollutants	Asbestos, various toxic metals, organic gases, gasoline vapors, incomplete combustion products, polycyclic aromatic hydrocarbons	Same as those mentioned above
Indoor Air Pollutants Other Than Radon	No significant ecological risks	Not applicable
Radiation Other Than Radon	Ionizing and non-ionizing radiation	Radio/TV frequencies, power lines, radar, microwave transmitters, high- and low-level radioactive wastes
Indoor Radon	No significant ecological risks	Not applicable
Global Warming and Climate Change	Carbon monoxide, carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons (CFCs)	Mobile and stationary sources of fossil fuel production and combustion, landfills, and agricultural practices
Stratospheric Ozone Depletion	Nitrous oxides and chlorofluorocarbons (CFCs)	Industrial processes, coal, oil, and gas combustion, fertilizer use, deforestation

Estimates of exposure should be based on the most likely scenarios, rather than on worst-case scenarios. The analysis should emphasize the most important, or "dominant," pathways of exposure. For example, pesticide use can harm terrestrial organisms that enter fields following application or because of overspray on adjoining lands. However, the dominant pathway of exposure for pesticide use may be runoff into aquatic habitats. While potential impacts to terrestrial animals and plants should be mentioned, the analysis should focus on impacts to aquatic organisms and habitats in this instance.

Finally, an analysis of uncertainty is an integral part of the analysis. In the majority of analyses, either data will not be available, or the data that are available may be of questionable or unknown quality. Typically, the analyst will have to rely on a number of assumptions to characterize exposure based on a combination of professional judgment, inferences based on similar instances of exposure, and estimating techniques—all of which contribute to the overall uncertainty of the estimate. It is crucial that the various sources and kinds of uncertainty are carried forward and noted in the third (risk characterization) phase.

Task 3: Characterize Ecological Effects

The next task is to combine information about the magnitude, timing, and location of exposure by ecological receptors of concern to various stressors. The data used to characterize ecological effects depend largely upon the nature of the stressor and the ecological receptor of concern. Ecological effects range from mortality of an individual species to disruptions in the structure and function of entire ecosystems. If possible, these ecological effects should be quantified, but often the relationship can only be described non-quantitatively.

Ecological effects can be analyzed at any level of biological organization (i.e., individual, population, community, and ecosystem). In fact, using data about ecological effects among different biological levels is recommended since each level is likely to provide only part of the overall "picture" of risks posed to an ecosystem and communities. For example, ecological effects might be measured in terms of the reproductive impairment of a given population; the changing structure of a community of plant and animal species; or the functions provided by ecosystems, such as nutrient and energy cycles.

Sources of ecological effects data include field observations (e.g., fish or bird kills), field tests (e.g., microcosm or mesocosm tests), controlled laboratory tests (e.g., single species), and chemical structure-activity relationships. For chemical stressors, a combination of modeling and monitoring data is often used; for non-chemical or physical stressors, data provided through ground reconnaissance, aerial photography, or satellite imagery can be used. In either case, it is often necessary to use professional judgment to supplement existing data.

Ecological risks can be described quantitatively (e.g., there is a better than 50 percent chance of 20-30 percent mortality in a given population) or non-quantitatively (e.g., there is a high likelihood of mortality occurring in this population). Information on the types and magnitude of uncertainty can provide risk managers and decision makers with greater insight into the strengths and weaknesses of the analysis. This knowledge can also indicate problem areas where further research to reduce uncertainty may be worth the investment, as opposed to other environmental problems with relatively little uncertainty where response actions can be implemented immediately.

PHASE 3: RISK CHARACTERIZATION

The third phase of a comparative ecological risk analysis involves using the results of the analysis phase to characterize the environmental risks posed by problem areas. Risks are characterized by pulling together all the information gathered and analyzed about stressors, receptors, and ecological effects. This information is typically described in terms of the number of acres or stream miles at risk, measured concentrations of stressors found in the environment, the magnitude and severity of effects, their spatial and temporal distribution, and the ecosystem's recovery potential and rate. Risk characterization also includes a summary of assumptions and scientific uncertainties.

For most problem areas, professional judgment will have to supplement existing data in terms of extrapolating or interpolating information from other studies. All of these judgments introduce uncertainty and imprecision to the analysis, but they also help analysts more fully and clearly describe the extent and severity of the impacts and potential risks to the environment. For example, an observed ecological effect might be the decreased reproduction of peregrine falcon hatchlings in areas of high pesticide use. In addition, lab tests may indicate that pesticides are also lethal to many other organisms, such as field mice and microbial organisms, that occupy the same habitat and that may be indispensable for that particular ecosystem to function normally. Therefore, the work group might determine that pesticides pose serious threats not only to highly visible and endangered species like the peregrine falcon, but also to the entire ecosystem.

While these latter effects may not capture the general public's attention, they may be far more important ecologically. This exemplifies the divergence that can sometimes occur between the social or political significance of an ecological receptor and its biological significance. Creating a risk communication dialogue between the scientific community and the public can make the risk analysis process an educational opportunity for all parties involved.

Task 1: Summarize Each Problem Area Using Evaluative Criteria

The first task of the risk characterization phase is to characterize each problem area in terms of the evaluative criteria. This should be done for each ecosystem or geographic area. If the project is partitioned into ecosystems, then the ecological risks to each ecosystem would be scored or described; if the project is partitioned by geographic area, then each geographic area would be scored or described. Table 2.3.2 provides a hypothetical example of this to describe the impact of pesticides in different geographical areas of California. This would be done for each problem area and, preferably, during work group meetings.

Table 2.3.2:
Hypothetical Pesticide Example

Geographic Areas	Area of Impact	Severity of Impact	Reversibility	Uncertainty
Coastal Range	Low	Medium	Medium	Medium
Sacramento Valley	High	High	High	Low
Southeastern Calif. Desert	Low	Medium	High	Low
Sierra Nevada	Low	Low	High	Low
Los Angeles Bight Habitat	Medium	Low	Low	Medium
San Joaquin Valley	High	High	High	Low

Criteria can be described narratively or scored numerically. There are advantages and disadvantages to each approach. The advantage of the narrative description approach is its simplicity and flexibility. It does not tie work group members to a rigid formula. For less quantitative members, it is likely to be more comfortable and intuitive to discuss risks and impacts in common terms. The disadvantage of this approach is that because project participants may not weigh evaluative criteria consistently, the final ranking may not be replicable if done by another group of people using the same information. It is also difficult to backtrack through the rationale for the ranking if the only reason given for decisions is that it was the "sense of the group." Table 2.3.3 provides another example of how this narrative approach might be assembled to describe the ecological impacts of pesticides. The descriptions in the table are purely conjectural.

Table 2.3.3:
Hypothetical Narrative Description for Pesticides

Geographic Areas	Total Risk	Comments	Uncertainty
Coastal Range	Medium	Potentially large area "at risk," but not a serious threat to ecosystem.	Medium
Sacramento Valley	High	Almost entire area affected at high dosages; serious, widespread impacts.	Low
Southeastern Calif. Desert	Medium	Small area "at risk," but potential threat is serious; fragile ecosystem.	Low
Sierra Nevada	Low	Low probability of impact; not considered a serious threat to ecosystem.	Low
Los Angeles Bight habitat	Medium Low	Impacts unknown, but large area "at risk"; diverse, fragile ecosystem.	Medium
San Joaquin Valley	High	Entire area affected at high dosages; serious, widespread impacts.	Low
Total Risk	**Medium**	**Serious, but reversible damages. Affects large area, but not entire state.**	**Low**

Alternatively, the ecological work group might feel more comfortable attaching numeric values or "scores" to each criterion. In contrast to narrative descriptors, numeric values can be manipulated mathematically and resolved to a single number. Thus, ecological risk can be expressed as a mathematical formula that is designed to increase as the size of the area affected increases, the severity of the effect increases, and/or as the length of recovery by the ecosystem increases. Various weights can be attached to each criterion by placing coefficients in front of the variables to reflect their relative importance. The results can then be compared for different problem areas. The disadvantage of this type of formulaic approach is that it can convey a false sense of certainty and precision. In addition, the public may not relate to a complex formulaic approach, and this could discourage public participation and interest. Exhibit 2.3.6 shows how numeric values can be used instead of narrative descriptors.

The approach selected will depend upon the preferences and objectives of those designing the project. Numeric or narrative scoring systems can both effectively organize and summarize large volumes of information, and they force people to evaluate the impacts of problem areas more systematically and consistently. However, they only reflect the collective judgments of those assigning values to them, and they are only as sound as the underlying analyses. Scoring systems should not obscure this fact or become so elaborate as to be unintelligible to the public.

Exhibit 2.3.6:
Narrative and Numeric Scales for Evaluative Criteria

Narrative Descriptor	Desciption of Severity	Numeric Value
Very High	Ecosystem structure and function are severely damaged and fundamentally changed by stressor(s). Ecosystem is rendered virtually lifeless.	4
High	Ecosystem structure and function are seriously damaged by stressor(s). Species populations decline and communities change. Habitats and abiotic resources are lost.	3
Medium	Ecosystem structure and function are adversely affected by stressor(s). Impact is infrequent or intermittent; individuals may die, but populations are not at risk; habitat is intact.	2
Low	Ecosystem structure and function are exposed to stress, but the structural and functional integrity are intact. Temporary and mild impacts to species individuals or habitats occur.	1
None	Ecosystem structure and function are not exposed to stress, or expression of stress is not measurable or adverse.	0

Task 2: Summarize the Risk to Each Ecosystem or Geographic Area

The second task is to summarize the overall risk to each ecosystem or geographic area in terms of all the evaluative criteria. This value represents the "total" risk to each ecosystem or geographic area. Building upon the previous information on pesticides only, Exhibit 2.3.7 provides an example of how this information can be integrated into a larger matrix that includes all the problem areas.

Task 3: Aggregate Risks Across Ecosystems or Geographic Areas

The third task is to aggregate the risks for each problem area across all the ecosystems or geographic areas within the study area. The bottom row of Exhibit 2.3.7 depicts the total hypothetical risks associated with pesticides.

There is no "correct" way of aggregating the values across ecosystems or geographic areas. However, a number of methods and approaches, such as group discussion and consensus building, have already been discussed. Given the broad mandate to set general environmental priorities on the basis of risk, participants in past comparative risk projects have been able to reach agreement on rankings and make these distinctions with some confidence.

As was stated at the outset of this discussion of the risk characterization phase, it is not important where the distinction is drawn between risk characterization and comparing and ranking problem areas. It is a single process that must be conducted in a sequential order of steps. The steps described in this section provide the raw material for comparing and ranking problem areas.

Exhibit 2.3.7:
Summary Table of Ecological Risks Across All Problem Areas

Sample Problem Areas ↓ / Sample Geographic Areas →	Coastal Range	Sacramento Valley	Southeastern Calif. Desert	Sierra Nevada	L.A. Bight	San Joaquin Valley	**Total Risk by Problem Area**
Environmental Lead							
Hazardous Waste Sites							
Non-point Source Pollution							
Pesticides	Medium	High	Medium	Low	Medium	High	**Medium/ High**
Sulfur Oxides and Nitrogen Oxides							
Physical Degradation of Aquatic Habitats							
Total Risk by Geographic Area							

PHASE 4: COMPARISON AND RANKING

The final phase of a comparative ecological risk analysis involves comparing and ranking the ecological risks posed by different problem areas. This is done by considering the ecological impacts and risks for each problem area in terms of all the evaluative criteria taken together and comparing them to the other problem areas. Problem areas are then grouped into several broad categories of relative risk using a consensus-building process. Professional judgment plays a critical role, but the level of precision required is only enough to make rough relative comparisons, rather than absolute estimates, of risk.

During the comparison and ranking phase, the total risk values for each problem area that have been described are assembled into a matrix. At this point, with all the information in the problem area risk characterizations and evaluative-criteria summary tables at their disposal, the ecological work group, steering committee, or public advisory board can rank problem areas. The methods and ranking approaches discussed in Section 2.1 can be used and adapted to each project. A matrix can also be used to identify those ecosystems or geographic areas at greatest risk.

The resulting ecological ranking is used as an important input to the risk management process, which takes into consideration relevant non-risk factors in addition to the risk ranking results to help set environmental priorities.

End Note

[1] The term "receptor" is used here for ease of understanding. However, in other technical documents it has been replaced by the term "ecological component" because some believe that this term communicates the tact that ecological risk assessments focus on components of ecosystems at higher levels of biological organization than the individual organism. As used here, the two terms are synonymous.

References

Colorado. Department of Health and Department of Natural Resources. *Environmental Status Report: A Summary of the Technical Analysis of the Colorado Environment 2000 Project.* June 1990.

Hawaii. Center for the Department of Health. *Hawaii Environmental Risk Ranking Study: Environmental Risks to Hawaii's Public Health and Ecosystems.* Prepared by East-West Center. Honolulu, HI. September 1992.

Michigan. Department of Natural Resources. Michigan Relative Risk Analysis Project. *Michigan's Environment and Relative Risk.* July 1992.

Suter, Glenn W., II. "Endpoints for Regional Ecological Risk Analysis." *Environmental Management,* vol. 14, no. 1 (1990): 9-23. Oak Ridge, TN: Oak Ridge National Laboratory.

U.S. Environmental Protection Agency (U.S. EPA). Office of Research and Development. Risk Assessment Forum. *Framework for Ecological Risk Analysis.* Washington, D.C. February 1992.

U.S. EPA. Risk Assessment Forum. *Peer Review Workshop Report on a Framework for Ecological Risk Analysis.* Prepared by Eastern Research Group, Inc. Washington, D.C. September 1991a.

U.S. EPA. Office of Pesticide Programs. Ecological Effects Branch. *Comparative Ecological Risk Analysis: A Review and Evaluation of EPA Regional Methods.* Washington, D.C. January 1991b.

U.S. EPA. Region VI Headquarters. Office of Planning and Analysis. *Comparative Risk Project,* Appendix A. Dallas, TX. November 1990a.

U.S. EPA. Science Advisory Board. *Reducing Risk: Setting Priorities and Strategies for Environmental Protection,* Appendix A. Washington, D.C. September 1990b.

U.S. EPA. Office of Policy, Planning and Evaluation. Office of Policy Analysis. *Review of Ecological Risk Analysis Methods.* Washington, D.C. November 1988.

U.S. EPA. *Regional and State Comparative Risk Project Approaches for Ranking Based on Ecological Risk/Impact.* Prepared by ICF, Inc. Washington, D.C. December 1987a.

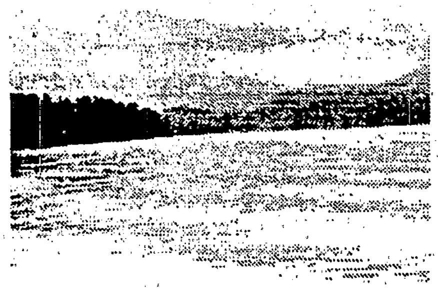
U.S. EPA. Office of Policy, Planning and Evaluation. *Review of the Literature on Ecological End Points*. Prepared by American Management Systems, Inc. Washington, D.C. September 1987b.

U.S. EPA. Office of Policy, Planning and Evaluation. Office of Policy Analysis. *Unfinished Business: A Comparative Assessment of Environmental Problems*, Appendix II. February 1987c.

Vermont. Agency of Natural Resources. *Environment 1991: Risks to Vermont and Vermonters*. Report by the Public Advisory Committee, The Strategy for Vermont's Third Century. Waterbury, VT. July 1991.

TABLES

EXHIBITS



2.4 Quality-of-Life Assessments

pristine natural resources far from their daily existence. Among the damage categories, health-care costs can have a larger impact on a low-income community if the costs consume a greater portion of the population's income. Many low-income families have no health-care insurance, leading to an even greater economic burden and added social stress.

The Seattle Environmental Priorities Project illustrated the importance and complexity of addressing community values in comparative risk assessment:

> Transportation sources of air pollution, wood burning, and environmental tobacco smoke are driven largely by individual choices that, cumulatively, pose significant risks to public health, the environment, and the overall quality of life in the city. What is the appropriate balance between individual values (such as personal mobility, convenience, and individual preferences) and community values (such as public health and environmental quality)? What is the city's role in identifying and achieving this balance?
>
> The information on quality-of-life risks is sparse at best. Many of these impacts are not measurable, at least not in a way that most people find meaningful; consequently, the Technical Advisory Committee's consideration of quality-of-life risks is entirely non-quantitative. The committee noted the type or types of quality-of-life concerns associated with each issue, and made judgments about the scale, severity, and reversibility of those concerns (Seattle 1991).

The process for assessing social and economic impacts is still being developed. Nevertheless, Exhibit 2.4.1 indicates a logical progression of information gathering and analysis. The following sections discuss these steps in detail.

Exhibit 2.4.1:
Steps in Quality-of-Life Analysis

Step 1: Identify impacts and determine the values of the community.

Step 2: Identify and define evaluative criteria.

Step 3: Collect and analyze data on impacts.

Step 4: Characterize impacts for all problem areas.

Step 5: Present findings and rank problem areas for quality-of-life impacts.

Step 6: Analyze future environmental conditions and risk management consideratons

STEP 1: IDENTIFY IMPACTS AND DETERMINE COMMUNITY'S VALUES

The values of a community are the basis for an analysis of the impacts of environmental problems on the quality of life. This step is important to ensuring that the process has

Computing the costs to society of continued pollution is in the interest of the government and the environmentally concerned community. This information can underscore the role of environmental quality with regard to sustained economic development and quality of life. In addition to the economic benefits of more traditionally recognized natural resources, such as oil, gas, minerals, and wood, ecosystems provide numerous services that would be extremely costly or impossible to replace. These include purifying polluted water (wetlands), producing oxygen (green plants), and protecting the earth against harmful ultraviolet radiation (the stratospheric ozone layer).

Comparative risk projects usually include an evaluation of the impacts of environmental problems on the quality of life. Historically, these evaluations have concentrated on economic impacts that can be readily quantified in dollars, such as health-care costs, crop losses, and damage to materials. These evaluations are particularly important to decision makers who must justify the expense of environmental protection measures to groups who are concerned with losing jobs or profitable business opportunities. In some cases, the information gathered can demonstrate that environmental protection may actually save money and maintain or create jobs.

Participants in the quality-of-life ranking usually include legislators and other government officials, educators at all levels, environmental groups, local industries and utilities, members of the general public, and spiritual, ethnic, and cultural leaders who represent the community's values.

This chapter encourages expanding quality-of-life analyses to include the values and social concerns of the community affected by the environmental problems, commonly missed in studies limited to health, ecological, and economic concerns. These values include spiritual, cultural, and aesthetic values, concern with the fairness of an environmental problem's impact on specific populations or future generations, and the value of one's sense of community. Relevant social impacts should be discussed explicitly, and decisions should be made regarding how best to describe, evaluate, and communicate the least quantitative elements of environmental effects on the quality of life.

Environmental equity should be considered throughout the assessment process. If the area under study includes a diversity of people and life styles, it may be necessary to pay particular attention to potentially serious impacts on particular groups of people. This topic is covered in more depth in Section 2.1 of this document, but is mentioned here to emphasize aspects of the quality of life that differ among cultural and economic groups. For example, the loss of animal habitats or sacred lands may adversely affect Native Americans' traditional life styles and, hence, their quality of life. Also, communities that depend on a single natural-resource-intensive industry, such as fishing or logging, are at risk if non-sustainable practices jeopardize their livelihood. Cultural and income differences may affect the baseline values used to evaluate impacts on quality of life. Willingness-to-pay models may have to be adjusted in light of different social norms. For example, residents of stressed urban communities may be more interested in enhancing their immediate environment (e.g., urban parks and cleanup of abandoned industrial plants) than in preserving biodiversity or

Exhibit 2.4.3:
Descriptions of Vermont's Quality-of-Life Criteria

Criteria	Descriptions of Criteria
Impacts on Aesthetics	Reduced visibility, noise, odors, dust, and other unpleasant sensations, and visual impact from degradation of natural or agricultural landscapes.
Economic Well-being	Higher out-of-pocket expenses fix, replace, or buy items or services (e.g., higher waste disposal fees, cost of replacing a well, higher housing costs), lower income or higher taxes paid because of environmental problems, net jobs lost because of environmental problems, and health-care costs and lost productivity caused by environmental problems.
Fairness	Unequal distribution of costs and benefits (e.g., costs and benefits may be economic, health, asethetic).
Future Generations	Shifting the costs (e.g., economic, health risks, environmental damage) of today's activities to people not yet able to vote or not yet born.
Peace of Mind	Feeling threatened by possible hazards in air or drinking water, or potentially risky structures or facilities (e.g., waste sites, power lines, nuclear plants), and heightened stress caused by urbanization, traffic, etc.
Recreation	Loss of access to recreational lands (public and private), and degraded quality of recreation experience (e.g., spoiled wilderness, fished-out streams).
Sense of Community	Rapid growth in population or number of structures, or development that changes the appearance and feel of a town; loss of mutual respect, cooperation, ability, or willingness to solve problems together; individual liberty exercised at the expense of the individual; and loss of Vermont's landscape and the connection between the people and the land.

broad support and represents public concerns accurately. Surveys, questionnaires, and public meetings are among the tools sometimes used to help reveal impacts and define community values. Major differences of opinion within values should be noted. Once the work group has gained a sense of the range of impacts and the community's values, the extent to which those values are degraded by impacts to environmental quality must be evaluated. Determining the values of the community involves: "working with community members to define "quality of life," then asking: what social values are most important in the community, which can be affected by environmental problems, and which will be important considerations when the community evaluates management strategies?"(NCCR 1992)

The Strategy for Vermont's Third Century (Vermont 1991) used public meetings, a survey, and research to determine shared values among Vermonters:

> After holding 11 public forums, conducting an informal public survey, and reviewing several statewide opinion polls, the Advisory Committee concluded that most Vermonters share a similar set of values relating to their environment. The committee adopted these as its seven quality-of-life criteria. [They are listed and defined in Step 2 of this section.]
>
> Because most of these seven criteria are intangible, they are extremely difficult to measure or quantify. The Quality-of-Life Work Group described how each problem area affects each criterion and how widespread or intense the effects are. Although these non-quantitative descriptions of risk often lack precision and scientific objectivity, they focus attention on specific critical issues and thus are useful tools for comparing the problems systematically and consistently.

Step 2: Identify and Define Evaluative Criteria

Criteria can be derived from broadly shared public values and applied to each problem area to determine how quality of life is affected. Comparative risk projects have varied in the criteria considered for quality-of-life impacts—from studies limited to the economic impacts of environmental problems, to those that included several social issues as well. Exhibits 2.4.2 and 2.4.3 and Table 2.4.1 list the criteria used by three comparative risk projects.

Exhibit 2.4.2:
Criteria Used to Assess Quality-of-Life Impacts

Louisiana	Seattle
(Qualitative Aspects of Losses)	*(Categories of Quality-of-Life Impacts)*
• Number of People Affected	• Reduced Recreational Opportunities
• Severity of Effects on Specific Populations	• Reduced Aesthetic Value
• Availability of Substitutes	• Reduced Economic Opportunities
• Reversibility of Effects	• Loss of the Intrinsic Value of Future Use of the Resource Affected
• Unaccounted Damages	

STEP 3: COLLECT AND ANALYZE DATA ON IMPACTS

Once criteria have been selected, the challenge is to find a way to measure the damage from each problem area. Projects may include both quantitative and non-quantitative analyses. The point is to have a well-defined analytic framework and a consistent set of criteria to apply to each problem area. The analytic methodology should be agreed upon in advance and documented as it is used for each problem area. Chapter 2.1 of this document provides more detail on general analytic structure.

Sources of Data

The data used to measure the criteria reflect the values of the affected community. The data usually fall into one of several categories:

Survey Responses. The range of data and units of measure in a survey are defined by the questions asked. For example, if a survey asks respondents to describe how air pollution affects the quality of life, a broad range of responses could be anticipated, including problems related to health, visibility, soiling, and psychological well-being. Units of measure for the responses might include the number of people reporting health problems, days of work missed, days with limited visibility, or days between visits to the carwash. Alternatively, if a survey asks how much money the respondent spent last year on health care related to air pollution, the only likely unit in the responses will be dollars.

Public Opinion Polls and Census Data. Information from these sources can help to indicate trends for the future of the area and can supplement other more direct data in determining community values.

Anecdotal Information. Responses from public meetings, surveys, etc., can be used in descriptive discussion of problem areas and in determining the values of the population.

Willingness-to-Pay Studies. For impacts on aesthetic and recreational values, willingness-to-pay studies have been used to provide a measure of damages in dollars.

Direct-Cost Data. This category includes information on health-care costs, crop loss, and structural damages that may be gathered from local sources or extrapolated from studies done elsewhere.

Non-market Data. This category includes measures of reduced visibility, noise levels, dust, unpleasant landscapes, and stress and related social disturbance. Vermont used innovative units of measure, such as "number of boil-water days," to measure losses due to turbidity of surface water, and photographs to indicate visibility loss due to air pollution. Days with public health advisories for air quality and bans on recreational and commercial fishing are other potential units of measurement.

Analytic Methods[1]

Analytic methods should include as comprehensive a picture as possible of the nature and extent of present and anticipated economic and social impacts caused by environmental degradation. However, models to predict future impacts are often unavailable or are

Table 2.4.1:
Vermont's Problem Areas and Quality-of-Life Criteria

Problem Areas	Vermont Quality-of-Life Criteria						
	Aesthetics	Economic Well-being	Fairness	Future Generations	Peace of Mind	Recreation	Sense of Community
Alteration of Vermont's Ecosystems	X	X	X	X		X	
Global Climate Change		X	X				
Indoor Air Pollution		X	X				
Air Pollution, Including Acid Rain	X	X	X	X	X	X	X
Depletion of the Ozone Layer		X	X	X			
Drinking Water at the Tap	X	X	X		X		
Pollution of Lakes, Ponds, and Streams	X	X	X	X	X	X	
Toxics in the Household		X	X				
Toxics in the Work Place		X	X		X		
Hazardous and Radioactive Waste			X	X	X		X
Solid Waste			X	X	X		X
Visual and Cultural Degradation of Vermont's Built and Natural Landscapes	X	X		X	X		X
Food Safety		X			X		
Ground-Water Pollution		X	X	X	X		
Loss of Access to Outdoor Recreation	X	X				X	
Pesticides & Pests		X	X				

region, or country (EPA 1986). Several EPA economic damage studies have used the following equation to estimate damages for total suspended particulates (TSP):

(Average TSP Level in ug/m^3 - Background TSP Level in ug/m^3) x Number of Households x Damages per Household per ug Change in Annual Mean TSP = Damages

The average TSP level can be derived by taking the mean of recorded TSP at all monitoring stations in the given state, region, or country.[2] Damage per microgram change in the annual geometric mean of TSP has been calculated to be roughly $1 per capita (1990 $).

This approach has only been applied with respect to particulate matter. Another approach that has been used to quantify damages to materials from a number of pollutants involves combining national estimates of per-capita damages with the population of the relevant state or region in the following fashion:

Annual National Per-Capita Damages x Population of Region/State = Annual Damages

Table 2.4.2: Quality-of-Life Effects Measured In EPA Regional Projects

Problem Areas	Health-Care Costs	Recreation	Commercial Losses	Materials Damages	Aesthetic Damages	Property Damages	Resource Restoration
Industrial Waste-Water Discharges	1, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4		3		1
Municipal Waste-Water Discharges	1, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6		1, 3		1
Aggregated Drinking Water	1, 3, 4, 6			3			4, 6
Aggregated Ground Water	1, 2, 3, 4, 6						1, 2, 6
Non-point Source Pollution	1, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6		1, 3	4	1
Physical Degradation of Water/Wetland Habitats		3, 4	3, 4		3	4	1, 6
Municipal Solid Waste	1, 3, 4					1, 2, 4	1, 2
Industrial Solid Waste	1, 3, 4					4	
Underground Storage Tanks	3, 4, 6						1, 2, 6
Active Hazardous Waste Sites (RCRA Program)	1, 2, 3, 4, 6					1, 2, 4	2
Abandoned Hazardous Waste Sites (Superfund)	1, 2, 3, 4, 6					1, 2, 4	1, 2, 6
Accidental Chemical Releases	1, 4		6			1	
Pesticides	1, 2, 3, 4, 6	4, 6	4			4	2, 6
SO_x, NO_x, and Acid Rain	3, 4	1, 2, 3	1, 3		1, 2, 3, 4, 6	1, 3, 4, 6	
Environmental Lead	1, 4, 6					4	1
Ozone and Carbon Oxides	4, 6						
Particulate Matter	4, 6		4	4, 6			
Hazardous Air Pollutants	1, 3, 4, 6			4, 6			
Indoor Air (Except Radon)	1, 2, 3, 4, 6	4				4	1, 3, 4, 6
Indoor Radon	1, 2, 3, 4, 6						1, 3, 4, 6
Criteria Air Pollutants	1, 2, 3		1, 2, 3	1, 2, 3	2		
Strat. Ozone Depletion	2, 4, 6		4	4			6
CO_2 and Global Warming			4		4	4	2, 6
Physical Degradation of Terrestrial Habitats	3	3, 4				4	6

difficult to fit to existing data. Also, certain economic and social impacts, such as those from lost ecosystem services, may clearly exist, but may be very difficult to measure. Other impacts, like ozone-related crop damage or damage to materials from acid deposition, are relatively clear and measurable. Additionally, some analytical methods (e.g., willingness-to-pay studies) may be controversial, especially when results are presented to people without an extensive knowledge of economics.

Which economic and social impacts to assess, which analytic methods to use, and whether to explore future impacts are among the early decisions of a quality-of-life work group. In addition to the traditional measures of economic and social damages discussed in this chapter, the work group may want to consider other aspects of the extent and severity of impacts on human communities, including:

- Lost benefits from ecosystems and other natural resources damaged by environmental degradation.
- The impact of social and economic trends on the environment.

Seven categories of economic damages have been applied in past studies: (1) damages to materials; (2) commercial harvest losses; (3) health-care costs; (4) recreational losses; (5) aesthetic damages; (6) property-value losses; and (7) remediation costs. The first five categories measure economic losses relatively directly . The last two categories—economic losses due to decreased property values and the economic costs of restoring contaminated resources—must be used carefully because they (1) may capture many of the same economic damages estimated by the direct methods and (2) may poorly reflect actual economic damages. Property-value losses and remediation (resource restoration) costs can be used as an alternative or a complement to the more direct damage measures.

Table 2.4.2 lists the categories of economic damages used by several of EPA's 10 regions in their assessment of environmental problem areas. (Numbers in the cells refer to the EPA region.)

Damages to Materials

In the context of economic damage assessment, this category includes the soiling, discoloration, erosion, peeling, and cracking of a variety of materials and structures. The economic impacts are the costs of repairing or replacing these items. Past comparative risk studies have identified criteria air pollutants and acid deposition as the primary destroyers of materials. Specifically, most studies have calculated:

- Soiling from suspended particulates
- Dye fading from nitrogen dioxide
- Damage to rubber tires from ozone
- Damage to painted surfaces, metals, monuments, etc., from acid deposition

This is only a limited set of possible damages. The work group should attempt to identify other materials and structures susceptible to damage from pollution.

One approach to estimating economic impacts from damages to materials has the advantage of directly incorporating the pollutant concentration in the specific state, often rely on preexisting studies. One approach is to scale national damage estimates according to the harvest share of the particular state or region. When using this approach, it is important to explicitly state the type of economic damage being discussed in the given study. Comprehensive economic studies will address both consumer and producer surplus losses caused by yield reductions. Other studies may only address producer losses attributable to decreased profits or consumer losses attributable to higher prices and/or decreased supply. Care should be taken to properly account for both types of damages.

Variations of the general "scaling" method, as well as alternative methods for assessing commercial harvest damages, are considered in the following subsections on losses to commercial agriculture, fishing, and forestry.

Agricultural Losses

Agricultural yields for some crops have been adversely affected by different types of air pollution. Past comparative risk studies have focused on the agricultural effects of tropospheric ozone (i.e., smog). One approach for calculating harvest losses due to ozone is to use preexisting estimates of the percentage reduction in crop yield that follows from a percentage increase in the ozone concentration. Such statistical relationships have been calculated for a variety of crops and can be located in a number of economic benefits studies (Adams et al. 1989, Heck et al. 1983). This relationship can be used in the following fashion:

Percentage Yield Reduction Per One Percent Increase in Ozone Level (Crop Z) x
Percentage Increment of Ozone from Background Level (EPA 1989a)[4] x
State/Region/Country Value for Crop Z Harvest = Producer Losses

This method essentially estimates the decrease in crop production and multiplies it by the per-unit value of the crop. Harvest values are readily available from the U.S. Department of Agriculture (or the equivalent agency for foreign countries). Data on ozone concentrations are available from state or national air-monitoring programs.

It should be noted that this method only partly captures the economic damages, since it addresses only producer losses, not consumer losses. Also, it does not incorporate the potential for price changes when agricultural yields are reduced; for example, a decreased corn yield may raise the price of corn, mitigating the economic losses experienced by producers. As such, it is an upper bound on producer losses.

This method is useful because it employs regional ozone data in combination with crop sensitivity. An alternative, simplified approach that does not rely on ozone data involves scaling national damage estimates, using the following general formula:

Region/State's Percent of the National Harvest of Crop x National Damage Estimate for Crop
= Total Annual Damages for Crop

National crop damage estimates are generally developed on a crop-by-crop basis so that the state or region's share of total production can be obtained by dividing state/regional production by national production of a given crop. These statistics can be easily obtained from the Department of Agriculture (or the equivalent in foreign countries) or even from the *U.S. Statistical Abstract.*

For instance, past studies have calculated dye-fading damages due to nitrogen dioxide by taking the nationwide damage estimate found in EPA's 1982 Criteria Document and dividing it by the U.S. population to get per-capita damages. The per-capita figure is then multiplied by the population of the state or region. Specifically, the following per-capita damage estimates have been used:

- In the 1982 Criteria Document, EPA estimated the per-capita damages from dye fading due to nitrogen dioxide to be roughly $1.76 (1988 dollars).
- A 1983 EPA study reported that annual damage to tires from ozone was $1.77 per vehicle (1990 dollars).
- A 1986 EPA study estimated that soiling and discoloration damage to industry from suspended particulates amounted to roughly $14.98 per-capita (1988 dollars).
- A study by Horst et al. estimated per-capita damages from acid rain to be roughly $11 (1988 dollars) (EPA 1986b).

The per-capita approach has a number of problems. Obviously, it does not incorporate information on regional pollutant levels. In addition, the studies are often highly uncertain. For example, the National Acid Precipitation Assessment Program contends that the function relating acid precipitation to paint and mortar damage in the Horst study overestimates the actual physical damage. These estimates are provided here only as a rough guide to the potential magnitude of damages. Rather than rely on these point estimates of per-capita damage, the analyst should attempt to bracket the damage estimate by either (1) varying assumptions in the above studies or (2) locating alternative estimates of per-capita damages.

Using these methods, past comparative risk studies have frequently estimated large economic impacts for damages to materials, particularly for criteria air pollutants and particulate matter. Some work groups have viewed the results with skepticism, especially when the calculations are not based on locally monitored concentrations of pollutants.

Commercial Harvest Losses

A number of air and water pollution problems can cause economic damages by reducing the yield of commercially produced crops, seafood, and forests. For instance, tropospheric ozone (smog) may impede the growth of certain crop species and reduce farm yields. This damages the welfare of both producers and consumers of the commercial products—producers because of lost profits and consumers because of decreased availability of goods and consequent higher prices. Therefore, the most appropriate measure of economic damage attributable to decreased harvests is the loss in consumer and producer surplus. In simple terms, consumer surplus is the extra value consumers get from a purchase beyond what is actually paid.[3] Producer surplus represents the revenue that a producer receives for a good, beyond what it costs to produce the good. In general, it can be thought of as the profit earned by producers.

Since measuring lost producer and consumer surplus requires relatively complex research into market supply-and-demand conditions, comparative risk economic damage estimates

This method is likely to overestimate producer losses because of a number of simplifications. First, it measures only producer losses and not potential consumer surplus losses. Second, it measures lost producer revenue, not lost producer surplus. Furthermore, it assumes that the amount of shellfish brought to market increases and decreases in proportion to the acreage open to shellfishing; this may not be the case if, for example, shellfishing can be intensified in non-polluted beds without jeopardizing long-term sustainability. Finally, like the agricultural estimates, this method does not account for price effects; a decreased catch may raise the price of shellfish, thereby mitigating producer losses.

Estimating economic damages due to lost commercial fishing for fin fish is more difficult than estimating those due to shellfishing. Designated fishing areas are not as well defined, making regulation of fishing habits more difficult. Furthermore, the existence of commercial hatcheries makes market effects less directly dependent on water quality. Most comparative risk studies, therefore, tend to rely on preexisting studies that assess economic costs associated with the pollution of major water bodies in the area.

Commercial Forestry Losses

The comparative risk study conducted by EPA's Region IV used two sources to estimate damages to commercial forestry. Expert opinion summarized in a 1989 EPA staff paper suggested reductions in the rate of forest growth of between 10 and 20 percent (EPA 1989a). These percentage reductions in timber harvest were applied in simulations of the U.S. Forest Service's Timber Assessment Market Model, which generated estimates of the change in consumer and producer surpluses. For example, at a growth reduction of 15 percent, national consumer surplus was reduced by $516 million, while producer surplus increased by $302 million for softwood and hardwood lumber and by $118 million for softwood and hardwood stumpage (1984 dollars). These national figures were scaled to Region IV based on forest production statistics.

As with agriculture and fishing, national damage data can also be scaled when calculating economic damages from reduced growth in commercial forests. As with agricultural crops, such damages are usually associated with increased ozone concentrations, although acid precipitation may affect forest productivity in relevant areas (e.g., the northeastern United States). Past comparative risk studies have scaled the estimates in large regional studies. For instance, Calloway et al. (1986) calculated consumer and producer losses attributable to reduced forest productivity in the eastern United States (EPA 1986a). The Region I and III economic damage studies used these results in conjunction with production information from state or national forest bulletins to arrive at region-specific damage figures.

It is important to note that estimates of forest damages hinge on estimates of the yield reductions caused by ozone and acid precipitation. The range of expert opinion on this subject is significant, reflecting the fact that the translation from laboratory impacts to field impacts is not well understood. Therefore, the need for an analysis of the range of possible outcomes should be stressed.

Health-Care Costs

Health-care costs in a comparative risk project are costs associated with the incidence of environmentally induced illnesses beyond illnesses that might occur in the absence of the

In the United States, national crop damage estimates have been developed by a number of researchers, with the most recent figures available from a 1989 EPA study. This study developed a range of national damage estimates, recognizing the importance of varying assumptions about the supply/demand framework in agricultural markets. Specifically, one set of assumptions assumed no agricultural market distortions due to the structure of subsidies. Another set of assumptions incorporated subsidies, but allowed for no supply responses in the form of acreage increases or other adjustments in agricultural policies. A final set of assumptions calculated the cost savings after accounting for subsidies, but also allowed for agricultural policy changes. These three different methods provided three widely varying estimates of national damage for each crop in the staff paper, leading to equally wide-ranging regional damage estimates. When possible, the analyst is encouraged to apply this type of sensitivity analysis to bracket the range of possible economic impacts.

Past comparative risk studies have also considered crop losses from sulfur dioxide and stratospheric ozone depletion using methods similar to those reviewed above. Losses from these environmental problems have been found to be minor relative to ground-level ozone damages, and in the case of ozone depletion, are subject to a greater degree of uncertainty due to limited scientific data on yield reductions. However, ozone depletion may cause significant future harvest damages (the merits of estimating future damages and calculating a present value are discussed in Step 4 of this section). Other environmental problem areas should be considered for possible contribution to crop loss and should be quantified where studies are available, or discussed where they are not.

Commercial Fishing and Shellfishing Losses

Discharges into water bodies from non-point sources of pollution, industrial point sources, and POTWs (point-of-transfer waste sites) can close off shellfishing in contaminated areas. The ideal method for estimating economic damages associated with such problems would be to evaluate consumer and producer surplus losses. Consumer surplus would be reduced because a smaller shellfish catch would raise the price of shellfish; producer surplus could be reduced because of reduced sales and/or the increased costs of shellfishing (e.g., boats may have to travel to more distant shellfish beds). However, given that the resources for such an assessment are beyond the scope of many comparative risk projects, producer losses can be approximated using the following equation for the value of a shellfish catch in a particular area:

$$\frac{\textbf{Value of the shellfish catch in the area under consideration}}{\textbf{Area Open to Shellfishing}} \times \textbf{Area Closed to Shellfishing} = \textbf{Producer Losses}$$

This method essentially derives a value per unit of shellfishing area (typically acres) and multiplies it by the number of closed acres. Statistics on the status of local shellfish beds and the value of shellfish harvests are readily available from the National Marine Fisheries Service in the U.S. Department of the Interior or from the National Oceanic and Atmospheric Administration. In foreign countries, data should be available from equivalent agencies. Once total damages are developed, they must then be apportioned to the various water pollution problem areas.

treating the illness, such as medicine, medical appliances, and nursing care. Indirect costs reflect the reduced productivity of individuals with the illness—most significantly, foregone earnings because of time taken off of work. A "human capital" approach is typically used to develop per-incident estimates of this foregone productivity. For fatal illnesses, such as cancer, the human capital approach first calculates what the individual would have earned over his lifetime using a discounted present value of estimated mean earnings. This is contrasted to the expected lifetime earnings of an individual with the illness, and the difference (in present-value terms) represents indirect costs. For less serious illnesses, indirect costs are typically measured in terms of restricted-activity days based on mean daily earnings. In most cases, indirect costs outweigh direct costs and should, therefore, always be considered when determining the costs of illness.

Incorporating health-care costs into the economic damage assessment may be perceived as double-counting the health impacts already covered in the human health section of the comparative risk study. However, it is important to recognize the distinction between physically enduring an illness and paying for health care. The rationale behind considering health-care costs is that the economic burden is one that is borne in addition to the pain and suffering of illness.

Recreational Losses

Since the theoretical nature of recreational damages (and many other damages) makes them more difficult to evaluate, comparative risk economic damage studies frequently rely on existing economic studies performed by academic researchers. These studies typically follow one of two types of valuation methodologies:

- *Revealed-preference studies* measure the behavioral relationship between improvement in the quality of a recreational (or other) resource and the increased recreational use of that resource. This behavioral relationship reflects the use value of the recreational resource.
- *Contingent-valuation (CV) studies* measure willingness to pay for a resource by asking respondents to place a dollar value on improvements in the quality of the resource. Depending on how the question is framed, this approach can measure both use and non-use value.[5]

The CV method uses surveys of experimental settings to elicit individuals' willingness to pay for changes in the availability of non-market goods, such as environmental quality. Typically, respondents are presented with a contingent, or hypothetical, market where they are given information on a particular good and are asked to bid on increases or decreases in the supply of the good. Although CV can measure use value, it is used most frequently to identify non-use (intrinsic) values for goods. For instance, we may be confident that people have an intrinsic value for the water quality of Lake Huron, even though many of them do not intend to ever use it; simply knowing the lake is clean is of some value to them. CV attempts to translate this "existence value" and other non-use values into concrete terms. These non-use values are closely related to many of the societal and non-quantitative issues currently considered in comparative risk studies.

environmental problem. Health-care cost assessments in comparative risk projects have typically concentrated on medical costs and the cost of lost work time. Indirect costs, primarily reduced productivity due to lost work time, are estimated on the basis of expected earnings for the time lost from work. The level of analysis can vary from rudimentary to more sophisticated estimates, depending on project goals and resources.

Calculation of health-care cost damages relies directly on the estimates of health incidents generated by the health risk portion of the comparative risk study. The basic method for calculating damages involves multiplying the number of health incidents by the total health-care costs applicable to that particular illness. For instance, if the health analysis estimates that indoor radon exposure causes 500 lung cancers per year, this figure is multiplied by the medical-care costs for lung cancer ($64,220) to arrive at health-care cost damages for radon ($32.1 million). High and low estimates of cancer and non-cancer cases can be used as upper and lower bounds of the economic damage estimate.

Table 2.4.3:
Health Effects and Associated Health-Care Costs (1990 $)

Health Effect	Direct Costs	Indirect Costs	Total Costs
Cancer (1)			
Non-specific	$ 16,424	$ 48,316	$ 64,740
Respiratory	12,949	51,271	64,220
Digestive	13,377	28,868	42,245
Urinary	15,144	24,405	39,549
Reproductive	16,262	23,534	39,796
Nervous system	21,093	118,113	139,206
Buccal cavity	19,050	34,273	53,323
Leukemias	15,867	60,353	76,220
Lymphomas	18,439	64,202	82,641
Other sites	15,609	29,824	45,433
Non-cancer			
Giardia (digestive system) (2)	1,947	627	2,574
Restricted-activity days (2)	6	38	44
Asthma (2)	6	43	49
Hypertension (3)	220	*	220**
Non-fatal heart attack (3)	*	*	60,000**
Non-fatal stroke (3)	*	*	44,000**
Lead exposure, screening (3)	*	*	3,000**
Compensatory education (3 years) (3)	*	*	2,600**
Headache (4)	*	7.50	7.50**
Eye irritation (5)	*	*	9.00**

SOURCES:
(1) Hartunian 1981
(2) Rice 1985
(3) EPA 1985a
(4) Hall 1989
(5) Chestnut 1987

* Specific costs are not available
** Costs shown in 1985 dollars

Table 2.4.3 summarizes the annual health-care costs associated with a variety of cancer and non-cancer illnesses. As shown, total health-care costs include both direct and indirect costs. Direct costs represent the value of goods and services involved in diagnosing and multiplied by estimates of consumer surplus associated with a fishing day, (as shown in the formula below).

The decrease in consumer surplus due to lost fishing days is the primary component of economic damages due to reduced recreational fishing opportunities. Other components are possible, but are more difficult to measure. For example, people who choose to continue fishing may seek out new areas to fish. If these areas are more distant than the option that has been polluted, the additional travel costs also may be a part of economic damages. Since the methods reviewed here do not capture such damages, they may undervalue the total economic impact. If resources are not available to pursue the method outlined in the paragraph above, the analyst may wish to consider a less rigorous approach. One alternative uses the following equation to calculate damages from a loss in recreational fishing:

% of Water Fishable x Annual Number of Fishing Days x
Willingness to Pay Per Fishing Day = Damages

Like the more detailed method presented above, this equation estimates the increase in recreational fishing days that would result in the absence of water pollution, and then multiplies it by the per-day value of these increased fishing trips (willingness to pay). Here, however, fishing days are assumed to increase proportionally to available fishing waters. State 305b reports (or equivalent documents in foreign countries) classify surface water according to whether it is boatable, fishable, or swimmable (swimmable being the cleanest level). It is suggested that the analyst divide the calculations according to surface water type, specifically fresh water and salt water. Past economic damage studies have used the National Survey of Fishing, Hunting, and Wildlife Associated Recreation for data on fishing days per state. A number of academic studies have performed surveys that determine the consumer surplus associated with a day of recreational fishing. Although these willingness-to-pay figures are highly dependent upon the geographical area and the type of fish, figures in Table 2.4.4 are representative of the average consumer surplus per fishing day in 1990 dollars.

Table 2.4.4:
Willingness to Pay for Recreational Fishing

Type of Fishing	Low Estimate	High Estimate
Freshwater Fishing	$23	$33
Saltwater Fishing		
Offshore	93	113
Pier	20	29

Source: Walsh 1988

The estimates in Table 2.4.4 are provided here only to suggest the potential magnitude of damages. Analysts should attempt to locate willingness-to-pay figures that are specifically geared to the types of fishing done in the state, region, or country (e.g., fly-fishing, surf-

Contingent valuation has been used increasingly by EPA and other organizations to characterize the more elusive economic benefits of environmental quality. For instance, EPA is currently sponsoring a CV survey to evaluate non-use values associated with ground-water quality. Although CV has played a limited role in past comparative risk studies (e.g., to value willingness to pay for visibility), methodological improvements and increased availability of studies make it more pertinent in future risk-ranking efforts. However, the method is subject to many criticisms and should, therefore, be used cautiously in policy-making procedures.

Willingness-to-pay studies based on CV methods are influenced by the knowledge and values of the respondents. For this reason, some economists and social scientists believe they may not accurately estimate the true value of a resource. Where other studies are not available, however, this method for valuing environmental goods may be useful. It should be noted that explanations will be necessary during presentations, and some participants may not be convinced of the validity of the findings. When studies are available, most analysts prefer to rely on travel costs or other measures of revealed preference to derive economic damages for non-market goods.

In general, the results of revealed-preference and CV studies can be combined with information from state water quality reports (305b reports) to arrive at recreational damage estimates for surface water. Specific approaches are described below for valuing lost recreational fishing and swimming opportunities. Many other forms of outdoor recreation exist, and an attempt should be made to find local studies of recreational activities. In one case, very significant losses were estimated in an evaluation of lost revenues from beach closures due to pollution (EPA 1991a). Cost estimates were based on decreases in beach-use fees and estimates of other expenditures typically associated with beach visits. Where studies do not exist, a non-quantitative description of possible damages is better than leaving the issue unaddressed.

Damages to Recreational Fishing

The Louisiana economic damage assessment presented a relatively complex but theoretically correct approach for valuing damages to recreational fishing. Only a summary description is provided here; for detailed guidance, the reader should refer to the Louisiana comparative risk document (1990).

In general, the method draws on a study by Vaughan and Russell that modeled recreational fishing as a three-step process involving the choices of (1) whether to fish, (2) what fish species to seek, and (3) how many days to spend fishing. In the first step, Vaughan and Russell developed a regression equation estimating the probability that a person will go fishing, given a change in the number of fishable acres in the state or region. This provides an approach for determining the increase in fishing participation resulting from improved water quality. In the next step, a second set of regression equations were used to estimate how this increased participation will be divided between rough (e.g., catfish) and game (e.g., bass) fishing. A final set of equations allows the user to translate increased participation into actual days spent doing each type of fishing. The increase in days can be

$$[(12.262\,(VR2 - VR1)) - (0.0647(VR2^2\ VR1^2))] \times CPI = \text{Annual Damages per Household}$$

where:

VR2	**=**	**annual average visual range after SO reduction (km)**
VR1	**=**	**annual average visual range before SO reduction (km)**
CPI	**=**	**consumer price index, all items, wage earners and clerical workers**

The coefficients in this model were developed by incorporating the results of five separate contingent-valuation studies of visibility. It may be useful to vary the assumptions on which the coefficients are based (e.g., vary the mix of contingent-valuation studies) to develop a range of damages per household (EPA 1988a, 1988c).[7]

The baseline visual ranges in the visibility benefits equation can be obtained using models in the sulfur oxide RIA that relate emissions to visibility, or from other sources, such as state air office data. The average annual visual ranges after SO reduction can be calculated by using the emission reduction models in the RIA or by assuming lower- and upper-bound visibility improvements (e.g., a lower bound of 5 percent improvement and an upper bound of 20 percent improvement over baseline).[8]

Once the visibility damages per household have been estimated, the total damages can be obtained by simply multiplying the per-household damages by the number of households in the state, region, or country. Due to the natural variation in visibility from one geographic area to the next, it may be best to perform the calculations on a state-by-state basis and sum the results to the regional level, if a regional study is being performed. Similarly, if a national study is being performed, calculations should be done on regional levels, and the effects summed to the national level.

The model described above is appropriate for valuing visibility in most geographic areas. However, certain states, regions, and countries may contain areas that inspire a greater willingness to pay for visibility. Visibility benefits for these areas can be calculated using the willingness-to-pay equation per vehicle trip per year provided below:

$$\text{Willingness to Pay for Visibility Per Vehicle-Trip Per Year} \times (VR2 - VR1)\ \text{Vehicle Trips Per Year} = \text{Annual Visibility Damages}$$

where:

VR2	**=**	**background visual range (km)**
VR1	**=**	**annual average current visual range (km)**

A number of willingness-to-pay studies have been conducted for national parks. These studies provide estimates of willingness to pay per vehicle mile per kilometer of visibility improvement. One study used in previous economic damage assessments estimates that willingness to pay for improved visibility at Mesa Verde National Park ranges from $0.02 to $0.04 (1990 dollars) per kilometer of visibility improvement (EPA 1990b). Vehicle trips per year can be calculated as the number of people visiting the Class I areas divided by the average number of people per vehicle (roughly 2.5). Data on numbers of people casting), as well as to the type of fish being sought and the geographical surroundings that affect the fishing experience. It is best to identify a range of willingness-to-pay estimates to bracket the overall damage estimate.

Damages to Recreational Swimming

Methods for estimating economic damages associated with lost swimming opportunities are very similar to those used for recreational fishing. In theory, the primary component of damages is the reduced number of days that will be spent swimming and the associated loss in consumer surplus.[6] The second method discussed above (the unit day value method) can also be used in the following fashion to estimate swimming losses:

% of Water Swimmable x Annual Number of Swimming Days x Willingness-to-Pay Per Swimming Day = Damages

The following sources can be used in these calculations and can be combined to determine damages due to reduced swimming opportunities.

- Saltwater swimming days may be estimated using the following equation (EPA 1985b):

  Population Within Coastal Area x Proportion of Population That Participates in Swimming x Number of Trips Per Person Per Year = Swimming Days

- Based on several studies, Walsh et al. (1988) estimated average consumer surplus per swimming day to be roughly $25 (1990 dollars). Estimates vary, however, and the analyst should attempt to locate studies geared to the state, region, or country in question.
- In the United States, state 305(b) reports can be used to determine the percent of water not swimmable.

Aesthetic and Visibility Damages

Aesthetic damages typically include odors, noise, reduced visibility, and unpleasant visual elements, such as litter. Willingness-to-pay studies and travel costs may be used to estimate losses. Among the costs factored in are losses to the tourism industry and supporting industries, such as hotels, restaurants, and car rental companies. Decreases in property values due to degraded aesthetic conditions may also be considered.

Visibility Damages

Economic damages from reduced visibility are typically associated with sulfur oxide (SO) emissions. Several EPA studies (Regions I, IV, and VI) have applied a model developed by EPA's Office of Air and Radiation to estimate these damages. The model estimates the annual visibility benefits associated with achieving various air quality standards for sulfur oxide emissions. These benefits are equal to the damages that are present due to existing sulfur oxide levels. Visibility benefits per household are estimated using the following equation:

applied in these analyses typically involves using academic studies of homeowners' willingness to pay to increase the distance between their homes and the waste sites. Three studies have been used to bracket damage estimates:

- Michaels et al. (1990) found that homeowners were willing to pay $86 to $838 (1986 dollars) per mile from uncontrolled hazardous waste sites in Boston.
- Smith and Desvouges (1986) found a willingness to pay of $330 to $495 (1984 dollars) for each mile from a hazardous waste landfill.
- McClelland et al. (1989) found average home prices to be $4,800 (1988 dollars) lower when residents expressed concern about a nearby Superfund site.

These estimates of damage per home are used in the following equation:

Number of Sites (e.g., Superfund, municipal solid waste) x Average Residences Within One Mile x Willingness to Pay to Avoid Living Within One Mile = Annual Damages

Past comparative risk studies have varied in their approach to estimating the number of residences within one mile of Superfund sites, RCRA facilities, municipal landfills, and other waste management sites.[9] One simple method is to calculate the average population density per square mile in the state, region, or country (population divided by land area in miles) and divide it by the average number of people per home; this provides a rough estimate of the number of homes within one mile of each site. Since the population density around waste sites may be significantly different from the average (e.g., Superfund sites may be in urban areas, municipal landfills in rural areas), a more detailed approach may be beneficial.

The analyst should bear in mind two significant uncertainties when using these property damage methods. First, the willingness-to-pay studies that are available apply to either Superfund or RCRA waste sites. It may not be appropriate to use these willingness-to-pay figures to estimate damages from municipal solid waste sites; however, studies specifically geared to municipal landfills, are not currently available. Second, the willingness-to-pay studies actually estimated damages for each mile added to the distance from the site. The studies do not provide concrete guidance on how this effect decreases with successive miles from the site—e.g., residents 10 miles from the site should not be willing to pay 10 times what they would pay to be one mile from the site. The method described above may underestimate damages, since it only calculates damages based on homes less than one mile from the site.

Resource-Restoration Costs

Society incurs economic costs when actions must be taken to restore a resource that has been contaminated due to residual pollution. For example, if a household's drinking-water supply is contaminated, the homeowner may have to pay to dig a new well. Resource-restoration costs are discussed separately from the direct-damage estimation methods because their use raises a number of potential problems. First, resource-restoration costs have the potential to double-count direct damages. For example, expenditures to reduce radon concentrations will prevent adverse health effects. As a result, the comparative risk visiting most Class I areas are available from the National Park Service (or the equivalent in foreign countries).

Other Aesthetic Effects

Aside from damages associated with reduced visibility, very few other aesthetic damages have been directly addressed in past economic damage studies. These damages area not necessarily excluded form the economic effects analysis, however, since property damage estimates are likely to reflect the aesthetic conditions near the house.

Some comparative risk studies have estimated aesthetic damages by drawing on a number of EPA benefits studies that have found aesthetic damages to be equal to some fixed percentage of recreational damages when considering surface-water pollution. For example, the Region I economic damage study estimated aesthetic damages for surface-water pollution problems to be between 40 and 70 percent of the recreational damages; however, this approach is very simplistic. Analyzing reductions in property value is a theoretically sound method for capturing the economic effects of aesthetic degradation (see below), but it also tends to capture other damages as well. As demonstrated in the Vermont comparative risk study, a non-quantitative treatment of the social damage posed by aesthetic degradation may represent a more effective alternative.

Property-Value Losses

One alternative measure of economic damage is the reduction in the value of property located near areas of potential environmental risk. For example, a house located near a hazardous waste landfill may experience a reduction in value that may or may not be realized in the market, depending upon whether the house is sold. Economic damage still occurs, however, even if the damage is unrealized.

In general, property-value losses may reflect health, aesthetic, recreational, or other damages that are already addressed in other components of the economic effects study. Because of the potential for double counting damages covered elsewhere in the economic effects assessment, it is important to be aware of what damages are actually being captured by a reduction in property values. A nearby hazardous waste landfill may cause home values to drop because of the threat of ground-water contamination and subsequent drinking-water exposure. Property values also may drop because of aesthetic impacts, such as odors or the unpleasant appearance of the facility. The facility may pollute a nearby pond, reducing recreational opportunities, such as fishing or swimming. Therefore, while property-damage estimates may add valuable information to the overall characterization of economic impacts, they should be used carefully. In particular, two uses are appropriate:

1. Calculating property damages for environmental problems where no alternative methods exist for measuring damages.
2. Properly coordinating property-damage estimates with other types of damage estimates (e.g., using them as an upper bound for damages attributable to a particular environmental problem).

In past comparative risk studies, property damages have been estimated for Superfund sites, RCRA hazardous waste management sites, and municipal landfills. The method

Past comparative risk studies have used a variety of estimates of the cost of remediating contamination of private and public (municipal) water supplies. Private wells can be remediated in the following ways:

- Each affected household can apply point-of-use treatment to purify contaminated water and make it suitable for consumption. Total capital costs range from $1,000 to $5,000, and annual operating and maintenance costs are between about $500 and $1,000 per year, depending on the degree of contamination (EPA 1991b).
- Supplies can be replaced by extending a hookup from a municipal system, costing between $2,300 and $17,500 (capital costs) per household, depending on the distance from the nearest existing municipal supply and the number of wells being replaced.
- Private wells can also be replaced by digging a new well. The cost for a new well varies greatly, depending on the depth to ground water and other geological factors. Past comparative risk studies have used capital cost estimates of between $3,500 and $7,500. This is consistent with models developed by EPA, which indicate that capital costs for a new private well are roughly $5,000, with annual operating costs of about $200 (EPA 1988b).

The analyst will need to take into account the specific conditions in the area to determine the remediation approach most appropriate for estimating damages to private wells.

Because of their size, municipal wells are much more costly to remediate than private wells. The following approaches are possible:

- Treatment of municipal wells is one option. Total capital and operating costs range widely, depending on the treatment method, the type of contamination, and the size of the water supply system. Existing EPA models estimate that for a system serving 2,000 people, total capital and operating costs are between about $360,000 and $1.2 million, respectively (EPA 1989b, 1989c).[11]
- The cost of replacing a municipal drinking-water supply is also subject to uncertainty. Existing EPA models estimate that a full municipal system serving 2,000 people has a capital cost of about $6 million, plus annual operating costs of about $41,000 (EPA 1988c). However, if the distribution main (or other equipment) from the original system is used, costs will be much lower; previous studies used the range $150,000 to $315,000.

Total damages can be estimated by combining figures such as these with the number of wells contaminated for each problem area.

Mitigation of Radon in Homes

Most economic damage studies have estimated the cost of preventing exposure to elevated levels of radon in homes. The following equation can be used for radon abatement costs:

Average Cost of Remediation x Number of Homes With Elevated Radon x % of Homes Remediated = Damages

analyst must ensure that the assessment counts either health effects or resource restoration costs, but not both.

A second, more fundamental problem with resource-restoration costs relates to the uncertain relationship between such costs and actual economic damages. In the past, comparative risk work groups have been tempted to use potential total remediation costs as a measure of the damages attributable to an environmental problem. However, this approach is incorrect because there is no simple association between the costs of cleaning up a problem and the societal benefits that are realized by eliminating the pollution. They often reflect the requirements of environmental legislation, rather than actual damages. For instance, it may cost $1 million to remediate a contaminated aquifer through pump-and-treat methods. If this is a remote, non-potable aquifer, the current economic benefits realized after the cleanup may be minimal. In this instance, the cleanup costs are a poor measure of the potential benefits that would be realized (i.e., the currently incurred damages).

The following section presents methods for estimating two types of resource restoration costs: (1) the costs of restoring drinking-water supplies in cases of well contamination and (2) the costs of mitigating radon exposure in homes.

Restoration of Drinking-Water Supplies

Other restoration costs that have been estimated in past economic damage studies include remediating drinking-water supplies and removing asbestos and lead paint. The basic formula for estimating the costs of replacing contaminated drinking-water supplies is:

Number of Wells Remediated Annually x Cost of Replacing or Treating Each Well = Capital Cost of Replacing Contaminated Water Supply

The assessment should focus on the number of wells remediated each year, as opposed to the number of wells contaminated. For example, in the Region VI economic damage assessment, the numbers of wells remediated were only a small fraction of those actually contaminated.

Because data on the number of wells remediated sometimes are difficult to find, past studies have relied on the expert opinion of regional personnel. In some cases, the number of contaminated wells has been used to compute an upper-bound cost. The number of contaminated wells associated with each problem area may be available from regional reports or data bases.[10] For instance, a data base supplied by the Region I Water Supply Office provided information on the types of water supplies contaminated and the source of the contamination (underground storage tanks, municipal landfills, and other sources). For Superfund sites, Region I's Site Information Tracking Effort data base was used. In Region IV, a survey of 34 Superfund sites found that roughly 2 percent of the sites contaminated drinking wells each year; this figure was used to extrapolate to the universe of Superfund sites in the region. In general, each state, region, or country will individually need to research the number of wells remediated and/or contaminated, since data sources will vary.

materials (PVC plastics), increase health-care costs, and reduce commercial harvests. The "snapshot" method that analyzes only present damages would place ozone depletion at or near the bottom of the economic damages ranking. This approach would mask the importance of the ozone depletion issue.

There are two solutions to the problem of increasing risk over time. One solution would be to extend the time horizon when assessing damages for all the problems on the comparative risk list. For example, damages could be discounted over 100 years to obtain a present value for damages for each issue. This approach has been avoided because of the complexity involved in forecasting damages far into the future, which would require analytic approaches well beyond the means of the comparative risk studies.

A second approach provides a less rigorous but more practical solution by considering annual damages occurring in different future years and discounting them to the present. This discounting places the annual damage estimates back on a par with the other annual estimates in the study, providing a consistent basis for the ranking process. Since this approach need only be taken with the limited number of environmental problems that have increasing long-term effects, it does not require substantial additional resources.

Estimating damages to commercial harvests from ozone depletion illustrates the general method for discounting future damages. The scientific literature does not provide definitive information on the impact of UV-B radiation on plants, so past economic damages studies have relied on a large range of potential yield reductions (EPA/UN 1986) A lower bound of no effect on yield has been combined with an upper bound of a 20 percent reduction in yield in past studies. This yield reduction can be multiplied by the current annual value of the crop in the state or region to determine actual crop damages.

To show that current risks from UV-B radiation are limited but will increase over time, it has been assumed that the 20 percent yield reduction will occur 100 years from now (in the year 2093). Present damage can be set to 1 percent of this future level and can be increased linearly over time by 1 percentage point each year.[12] For example, if the 20 percent yield reduction is expected to cause $300 million in damages in year 100, the damage in year one would be $3 million (1 percent of $300 million), the damage in year two would be $6 million (2 percent of $300 million), and so on. This calculation provides estimates of the annual harvest damages that will occur in various years in the future. These figures can simply be discounted back to the present and used as an estimate of current annual damages. The following equation summarizes this present-value calculation for this example:

$$\frac{\$3 \text{ million}}{(1+i)^1} + \frac{\$6 \text{ million}}{(1+i)^2} + \ldots \frac{\$300 \text{ million}}{(1+i)^{100}}$$

where i is the interest rate used to discount future effects. If desired, this present value can then be placed on a rough annual basis by dividing by 100 years or by some other annualization approach (e.g., multiplying by an interest rate).

When applying this method, the assumption is that different remediation techniques will be used at different radon concentrations. Past studies have divided radon concentrations into three ranges—less than 4 pCi/L, 4 to 20 pCi/L, and greater than 20 pCi/L. Concentrations over 4 pCi/L are generally considered to be of concern. In the United States, state-by-state data on the distribution of homes into these categories are available from surveys conducted by EPA's Office of Air and Radiation.

Once the distribution of radon concentrations in homes is known, the number of homes that remediate for radon must be estimated. While information on remediation rates is greatly lacking, studies have considered the percentage of homes tested in combination with the percentage of homes that remediate once elevated levels are detected. One source estimates that less than 5 percent of U.S. homeowners have tested for radon (Oge 1990). Contacts with radon testing and mitigation firms indicate that less than 10 percent of homes with elevated radon (greater than 4 pCi/L) are remediated. This suggests an overall remediation rate of 0.5 percent for homes with elevated radon.

As mentioned, the cost of remediation is assumed to vary with the radon concentration. The following cost figures, drawn from the EPA document *Radon Reduction Methods: A Homeowner's Guide* (EPA 1987) have been applied in past studies:

- For homes with radon concentrations between 4 and 20 pCi/L, remediation typically consists of sealing cracks and holes in the walls and floors of basements, at a cost of approximately $100 per home (1988 dollars).
- For homes with radon concentrations above 20 pCi/L, remediation may involve slab suction, air-to-heat exchange, or other ventilation systems that have an average cost of approximately $2,500 per home (1988 dollars).

Step 4: Characterize Impacts for All Problem Areas

The data are analyzed quantitatively to provide an estimate of the relative severity of impacts from each problem area and the number of people affected. Wherever possible, non-quantitative information is added to the description of the problem area. Consistent use of criteria and analytic techniques is important to the credibility of the assessment process.

To fully characterize economic damages, it is sometimes necessary to consider effects well beyond the immediate time frame and outside the traditional arena of economic valuation. Examples include long-term/increasing-risk problems, such as the effects of global warming, ozone depletion, and diminishing species diversity, and the economic valuation of complex ecosystems. Applying a defensible discount rate is a problem associated with assessing risks over a long time frame.

Long-Term Damages

The need for temporal adjustments to the economic damage assessment is best illustrated by an example. Although ozone depletion does not currently pose large economic damages, the problem is expected to escalate over time as the ozone layer is further damaged and as increased UV-B radiation reaches the earth. This radiation is likely to damage

STEP 5: PRESENT FINDINGS AND RANK PROBLEM AREAS

Quantitative and non-quantitative information is presented in written descriptions of each problem area and in charts, matrices, and other tools for comparison. A group of project participants, usually the quality-of-life work group or a policy-level committee advised by the work group, uses the information presented to develop a relative ranking of environmental problem areas for quality-of-life issues.

It is important to document the process and methods used in a comparative risk project. This is particularly true for quality-of-life issues, which may require controversial analytic methods or may involve values that are not universally shared. A clear statement of sources, quality, and extent of data, methods used, assumptions made, and degree of uncertainty in results will add to the credibility of assessments. Differing views and core values need to be clarified, respected, and addressed. Where expert opinion is used in the absence of data, it should be clearly stated. These elements should be explained briefly in an overview that can be understood by non-economists. Decisions should be made regarding how to explain the often controversial results and analytic methods of the quality-of-life assessment.

Establishing an Integrated Ranking

Quantitative elements of quality-of-life impacts can be presented side by side with non-quantitative descriptions of impacts that are less amenable to unit measurement. In fact, scoring methods like those described in this section have been developed to combine non-quantitative factors with dollar damage estimates (EPA 1990c).[13]

One approach in establishing an integrated ranking is to translate the non-quantitative information into a numerical form more consistent with the dollar damage estimates. Table 2.4.5 shows how one EPA region accomplished this. In the first step, a "high," "medium," or "low" label is established for each factor across problem areas. Next, a score is attached to these labels; for instance, the "highs" can be given a score of 10, the "mediums" a score of 5, and the "lows" a score of 1. Then, these scores can be added to obtain a total score, or each factor may be weighted according to the importance attached to it by the work group (as seen in Exhibit 2.4.4). This refinement allows certain factors to influence the final score more than less important ones.

The final step in this approach is to merge the non-quantitative score with the dollar damage estimates. Since the objective is simply an ordinal ranking of issues, this can be accomplished in a variety of ways. One approach would be to convert the dollar damage estimates into scores on a scale (e.g., a scale from one to five) or into "high," "medium," and "low" labels. Another approach would be to adjust the dollar damages upward when there are non-quantitative impacts for the problem area (EPA 1988c). A third approach would be to evaluate and rank problem areas in terms that best suit that problem rather than trying to convert all the information into a common metric. Each quality-of-life work group must decide for itself which approach it is most comfortable with. Exhibit 2.4.4 provides a synopsis of the quality-of-life problem-area analysis and ranking process used in the Louisiana Comparative Risk Evaluation (1991b).

Discount Rate

The discount rate used in this sort of present-value calculation reflects important policy assumptions. Higher discount rates (6 to 10 percent) suggest that future effects are significantly less important than current effects. Lower discount rates (1 to 5 percent) imply that damages imposed on future generations are only slightly less important than those occurring now. A discount rate of zero would eliminate devaluation of future effects. The economic damages work group should carefully determine what discount rate is appropriate. Analysts should review the literature on the use of discount rates in natural resource economics and consider performing sensitivity analyses that incorporate different discount rates (JEEM 1990).

Methods of this type can be used to calculate a number of categories of damage, including materials damage due to ozone depletion, and harvest damages, aesthetic damages, and damages from sea level rise due to global warming. This approach is very simplistic, since it ignores important factors, such as changes in the value of resources as they become more scarce. One alternative method is to explain the factors involved in future values and use an innovative presentation format to convey the importance of temporal issues. For example, one report has suggested arranging all economic effects in a matrix that non-quantitatively describes the recovery time for the resource in question (EPA 1990a).

Services From Ecosystems

The services provided by complex ecosystems include a range of important functions that, while extremely valuable to humans, frequently go unrecognized in the economic damage assessment. Recent studies performed for EPA have compiled existing analyses and have begun to establish methods for valuing certain sensitive ecosystems. One study presents an overview of services provided by wetlands and summarizes the economic methods used to value wetlands (EPA 1991d). While no one method yields an estimate of the value of all the services provided by wetlands, the report suggests that the total value of an acre of wetlands is in the range of $5,000 to $15,000. Another study prepared for EPA considers the value of forest ecosystems in the southeastern United States (EPA 1991c). In addition to market-based services considered in this section (e.g., recreation, timber production), the study examines the value of forest services, such as erosion control and flood control. For example, to estimate the damages caused by soil erosion, the report considers the costs associated with increased sedimentation of surface water (e.g., dredging costs).

Valuation methods such as these may be useful in future comparative risk studies, where economic damages attributable to physical degradation of terrestrial and aquatic habitats could be projected based on estimates of lost acreage and estimates of value per acre for the habitat. Where economic valuation is not feasible, damages to complex ecosystems can be incorporated in the consideration of social costs (as in the Vermont comparative risk analysis), or in terms of non-quantitative adjustments to the dollar-based ranking.

Exhibit 2.4.4: Louisiana's Quality-of-Life Ranking Process

Orientation
The work group was introduced to the EPA method of quality of life impact assessment during a two-day orientation for the Technical Committee in March 1990. Before ranking the problem areas, the group met nine times between April and December 1990.

Full List of Issues Chosen
The group began, as did all three work groups, by identifying the list of issues that the entire Technical Committee would examine.

Familiarization with Economic Analysis
In the Quality of Life work group, members did not assume sole responsibility for individual issue analysis, as was done in the Health and Ecology Work groups. Instead, the group met regularly with a consultant to become familiar with each of the damage categories for which he prepared an economic assessment.

Supplementing The Economic Considerations
In addition to the quantitative analysis performed, the Quality of Life work group decided to include several other kinds of losses in its ranking of issues.

Weighting Economic Analyses and Qualitative Work
The work group members considered at some length how to reconcile the quantitative information compiled by Dr. Farber with their qualitative assessment. The group was very uncomfortable with the quantitative information, because it was so incomplete for so many issues in which little or no data exist to associate costs to the losses society incurs as a result of these issues.

There is a significant amount of data in some areas. For example, many studies have been done estimating the cost of fishing and boating losses when water bodies have been closed because they do not meet the standard for these uses. However, no parallel studies have been conducted to determine the cost of lost opportunities to exercise when the air is so unhealthy that people cannot exercise.

It may not even be possible to associate costs with such losses. For example, does Louisiana suffer losses in tourism and new businesses locating here as a result of the publicity the state receives from its high ranking on the toxics discharge to the environment list?

The work group agreed to treat the overall value of the economic analyses as equivalent to the qualitative work. Therefore, the group decided to organize economic analyses into five levels, high to low, based on dollar values. The work group was then able to rate each issue according to six factors. It established weights for the different ratings (low=1, high=5), and the support staff then calculated rankings.

Alternative Ranking Schemes
The support staff provided four alternative ways to calculate rankings, by varying the weights attributed to the qualitative aspects. The work group examined the results produced by the four alternative ranking schemes.

Preliminary Ranking
The group decided to have four levels of priority in its ranking. Any issue that consistently remained in the same priority ranking across the four alternative schemes was ranked in that category.

Final Ranking
The work group's discussions focused on issues that received a different ranking, depending on the scheme used.

Table 2.4.5:
EPA Region I Presentation of Results

Problem Area	# of People Affected	Subpopulation Effect	Availability of Substitute	Reversibility of Effects	Actual/Theoretical Costs	Uncertainty	Weighted Total Score	Midpoint Damages*
Criteria Air Pollutants	High	High	High	Low	Low	Low	4.6	$538.489
Acid Deposition	High	Low	Medium	Medium	Low	Low	1.9	$403.851
Hazardous Air Pollutants	Low	High	High	Low	High	Medium	7.1	$8.190
Indoor Radon	Medium	High	Medium	Low	High	Medium	7.1	$132.813
Indoor Air Pollutants	Medium	High	Medium	Low	High	High	9.1	$3.4715
Industrial Point Sources (Rivers and Streams)	Medium	Low	Low	Low	Low	Low	1.2	$10.930
Industrial Point Sources (Lakes and Ponds)	Medium	Medium	High	Medium	Low	Medium	4.7	$0
Industrial Point Sources (Oceans, Coasts, Estuaries)	High	Medium	Medium	Medium	Medium	High	7.3	$4.378
Municipal Point Sources (Rivers and Streams)	High	Low	Low	Low	Low	Low	1.5	$24.185
Municipal Point Sources (Lakes and Ponds)	High	Medium	High	Medium	Low	Medium	4.9	$0
Municipal Point Sources (Oceans, Coasts, Estuaries)	High	Medium	Medium	Medium	Medium	High	7.3	$39.4
Non-point Sources (Rivers and Streams)	High	Low	Low	Low	Low	Low	1.5	$81.089
Non-point Sources (Lakes and Ponds)	High	Medium	High	Medium	Low	Low	3.3	$132.942
Non-point Sources (Oceans, Coasts, Estuaries)	High	Medium	Medium	Medium	Medium	High	7.3	$43.778
Wetlands	Medium	Medium	High	High	Low	High	6.9	$20.405
Drinking Water	Low	High	Medium	Low	High	Medium	6.9	$12.610
RCRA Waste Sites	Medium	High	Medium	Medium	Low	High	7.9	$2.942
Superfund Waste Sites	Low	High	High	Medium	Medium	High	8.6	$6.104
Municipal Waste Sites	Low	High	Medium	Medium	Low	High	7.7	$15.852
Industrial Waste Sites	Low	High	Medium	Medium	Medium	High	8.3	$0.246
Accidental Chem. Releases	Low	High	High	Low	High	High	9.1	$27.863
Storage Tank Releases	Low	High	Medium	Medium	High	High	9.1	$0.6
Ground-Water Releases	Low	High	Medium	Medium	High	Medium	7.1	$2.275
Pesticide Residue and Application	Low	High	High	Low	High	Medium	7.1	$34.750
Environmental Lead	Medium	High	High	Low	High	High	9.3	$102.650
Asbestos	Medium	High	High	High	High	Medium	7.8	$38.275

* Dollar damage estimates in millions.

KEY TO RANKING CRITERIA

Weighting Factors:

Factor	Weight
Number of People	= 0.05
Effects on Subpop.	= 0.30
Substitutes	= 0.05
Reversibility	= 0.05
Actual/Theoretical Costs	= 0.15
Uncertainty/Bias	= 0.40
Sum of Weights:	= 1.00

Scoring Factors:

High = 10
Medium = 5
Low = 1

Example of how to calculate weighted total score for Criteria Air Pollutants:

(10 x 0.05) + (10 x 0.30) + (10 x 0.05) + (1 x 0.05) + (1 x 0.15) + (1 x 0.40) = 4.6

Table 2.4.7: Louisiana Quality-of-Life Damages Matrix

Problem Areas	Number of People Affected	Severity of Effects	Availability of Substitutes	Reversibility of Effects	Unaccounted Damages	Financial Losses
Indust. Waste-Water Discharge	High	High	Medium	Medium	Med/Low	Med/High
Munic. Waste-Water Discharge	High	High	Low	Low	Med/Low	Med/High
Drinking Water Supplies	Medium	High	Medium	Low	Med/Low	Low
Non-point Sources	High	High	Medium	Medium	Med/Low	High
Loss of Coastal Wetlands	High	High	Medium	High	High	Med/Low
Loss of Inland Wetlands	Medium	High	Medium	Low	Medium	Low
Ground-Water Contamination	Low	High	Medium	High	Low	Low
Storage Facilities	Low	Medium	Low	Low	Low	Low
RCRA Hazardous Waste Sites	Low	Low	Low	Medium	Medium	Medium
Superfund Haz. Waste Sites	Medium	High	Medium	Low	Med/High	Medium
Munic. Solid Waste Sites	Low	High	Medium	Low	Med/Low	Med/Low
Indust. Solid Waste Sites	Low	Medium	Medium	Low	Med/Low	Med/Low
Accidental Chemical Releases	Low	High	Medium	Low	Med/Low	Med/Low
Pesticides	High	High	Medium	Low	Med/Low	Med/High
Sulfur Oxides	Low	Low	Medium	Low	Low	—
Ozone, Nitric Oxides, and Carbon Monoxide	High	High	Medium	Low	Medium	—
Airborne Lead	Low	High	High	High	Low	—
Particulate Matter	Low	Low	Low	Low	Med/Low	High
Air Toxics	High	High	Medium	Low	Medium	Med/Low
Indoor Air Pollution	High	Medium	Medium	Low	Medium	High
Naturally Occurring Radon	Low	Low	Low	Low	Low	Low
Radiation	High	Medium	Low	Low	Low	Medium
Terrestrial Habitat Loss	Medium	High	Medium	High	Med/Low	Low
Aesthetics	High	High	Medium	Medium	Med/High	Medium
Strat. Ozone Depletion	High	Medium	Medium	High	Medium	Med/Low
Global Warming/CO_2	High	Low	Medium	High	Med/High	High
Deep-Well Injection	Low	Medium	Medium	High	Med/High	Low
Floodplain Development	High	High	Low	Medium	Med/High	Med/High
Natural Resources	High	Medium	Medium	Medium	Medium	Low
Oil & Gas Wastes	Medium	High	Medium	Medium	Med/High	Med/Low
Worker Exposure	Medium	High	Medium	Medium	Medium	Med/Low
Seafood Contamination	High	High	Low	Medium	Med/Low	Medium
Consumer Exposure	High	Medium	Low	Low	Medium	Med/Low

Based on the information available from an economist and the work group's best professional judgment, each problem area was rated as high, medium, or low, as it related to the following factors:

Number of People Affected — This parameter accounts for the percent of the state's population affected by the damages associated with the problem area—for example, people who can no longer swim in water posted by the state as unsafe. The following guidelines were applied to rank the problem areas:

High	**More than 1 million people affected (23% of LA population)**
Medium	**10,000 to 1,000,000 affected (0.2% - 23%)**
Low	**Less than 10,000 affected (0.2%)**

Severity of Effects on Subpopulations — This parameter is a measure of the extent to which the issue imposes damages on subpopulations. For example, if oyster beds are closed due to contamination, then those who make their living catching oysters would be a subpopulation that disproportionately suffers from this problem.

High	**Significant impact on subpopulation**
Medium	**Moderate impact on subpopulation**
Low	**Low or no impact on subpopulation**

Summary Tables

Another basic presentation tool is a summary table that gathers together relevant information on economic damages. Table 2.4.6 provides the midpoint of the range of estimated dollar damages, as well as the weighted total scores. Adding a comments column would allow the analyst to communicate the major uncertainties in the estimates and the biases these uncertainties may introduce.

Table 2.4.6: Sample Summary Table

Problem Area	Midpoint Damage Estimate	Upper-Bound Estimate	Lower-Bound Estimate	Comments
Storage Tanks	$850,000	$2,000,000	$300,000	Primarily cost to remediate drinking water; upward bias due to uncertainty about # of wells requiring replacement.
Indoor Radon	$9,000,000	$19,000,000	$1,000,000	Primarily health-care costs.

The Louisiana Comparative Risk Project (1991a) was conducted as the basis for the *Louisiana Environmental Action Plan, LEAP to 2000.* It included a quality-of-life damage category for "unmonetized damages" to supplement quantitative assessments of monetized damages. Some of the non-quantitative damage categories could theoretically be quantified, but little or no data were available. Table 2.4.7 illustrates categories of economic and social impacts evaluated by participants in the Louisiana project.

- *Taxes and user fees.* To a certain extent, taxes and user fees determine the behavior of individuals and industries in an area. For example, a relatively high fee for water may discourage excessive use, and a significant tax on gas guzzlers may encourage people to buy more efficient automobiles. Surface-water, ground-water, and air pollution are among the problem areas that could be affected. A future-oriented assessment of environmental problem areas should consider the consequences incentives of this kind might have for the quality of life.
- *Judicial and enforcement systems.* Enforcement systems currently in place may also affect the level to which a problem is presently controlled. If those systems were removed, certain environmental problem areas might degrade and could have negative impacts on the quality of life.
- *Regional needs for energy, water, and sewer services.* Population and economic trends affect the future needs of a community for water treatment, energy generation, and sewerage. Salinization of soils and water bodies, combined sewer overflows, and power plant emissions are among the problem areas that might have increased impacts on the quality of life.

Several comparative risk projects have discussed the question of how to include a longer-term viewpoint in their assessment of environmental problem areas to capture increases or decreases in risk over time. For example, EPA Region IV incorporated estimates of future demographic, transportation, and industrial trends in its comparative risk analysis (EPA 1992). Issues likely to change over time are often discussed generally in non-quantitative descriptions of the problem areas. While a more rigorous analysis can add an important dimension to the assessment, quantitative models designed to add a temporal dimension to the analysis may involve many assumptions, some of which may be controversial. Section 2.1 of this document discusses general analytical issues including problem area changes over time.

Availability of Substitutes — This parameter measures the extent to which substitutes are available to replace the quality-of-life losses associated with the issue. For example, if a water body is closed to swimming, is another water body available nearby that people would use as a substitute?

High	**No substitutes are available**
Medium	**Some substitutes are available**
Low	**Substitutes are readily available**

Reversibility of Effects — This parameter is a measure of the degree to which the damage caused by an issue is reversible over a short period of time. For example, runners might decide not to run on a day when ozone levels are high, but could run again as soon as the ozone returned to a healthy level. In contrast, wetland loss is irreversible. Louisianans will never again be able to birdwatch in the lost wetlands.

High	**Irreversible**
Medium	**Fully reversible after 10 years**
Low	**Reversible within 10 years**

Unaccounted Damages — The work group developed this category to capture any losses that were not considered under the economist's analysis. This category also includes the impacts for which the economist could not develop an estimate. The work group brainstormed during the entire first day of their ranking retreat and listed out all aspects they believed relevant. The work group did not identify objective criteria to determine a score for unaccounted damages. Instead, they reviewed the list of problem areas and assigned scores on a case-by-case basis.

Step 6: Evaluate Risk Management Issues

While risk management considerations should be kept separate from risk assessment, it is still important to anticipate and discuss future changes in environmental risk. For the findings of a comparative risk project to remain relevant on a long-term basis, population growth and the values of the community regarding development choices need to be considered. For example, land-development choices to build housing, roads, and factories or to protect natural habitats and tourist attractions will be affected by demographic trends and will influence the future risks posed by environmental problems. Cleaner industrial processes, substitute chemicals, efficient agricultural processes, and other technological innovations may also affect the future risks associated with problem areas.

Examples of how population and trend information can affect analysis of environmental problem areas include:

- *Industrial viability.* Trends in international prices, taxes, incorporation laws, etc., will affect the ability of certain industries to produce goods competitively. The future of many environmental problems will be affected by the survival and level of activity of specific industries in an area. If, for example, a drop in the price of oil or in the productivity of wells were to stop production in a given locale, oil spills, coastal habitat destruction, and other forms of air, water, and land pollution might be eliminated. It is important to know whether a given industry will survive economically when assessing its long-term impacts on the quality of life.

References

Adams, R.M, J.D. Glyer, S.L. Johnson, and B.A. McCarl. "A Reassessment of the Economic Effects of Ozone on U.S. Agriculture." *Journal of Air Pollution Control*, vol. 39 (1989):960-968.

Calloway, J.M., R.F.Darwin, and R.J. Nesse. *Economic Effects of Hypothetical Reductions in Tree Growth in the Northeastern and Southeastern United States*, prepared for U.S. EPA under a Related Services Agreement with the U.S. Department of Energy (Contract No. DE-AC06-76RLO 1830) by Pacific Northwest Laboratories. August 1986.

Chestnut, Lauraine, et al. *Santa Clara Criteria Air Pollutant Benefit Analysis*. Santa Clara, CA. May 1987.

Hall, Jane, et al. *Economic Assessment of the Health Benefits from Improvement in Air Quality in the South Coast Air Basin*. Final Report to South Coast Air Quality Management Board. June 1989.

Hartunian, N.S. *The Incidence and Economic Costs of Major Health Impairments*. Lexington, MA: Lexington Books, D.C. Heath and Co. 1981.

Heck, Walter, et al. "A Reassessment of Crop Loss from Ozone." *Environmental Science and Technology*, vol. 17. no. 12 (1983): 573A-581A.

Journal of Environmental Economics and Management (JEEM), vol. 18, no. 2 (1990).

Louisiana. Department of Natural Resources/U.S. Environmental Protection Agency. *LEAP to 2000: Louisiana Environmental Action Plan*. June 1991a.

Louisiana. Department of Natural Resources. "Comparative Risk Project: Briefing Memorandum on Quality of Life Analysis." Baton Rouge, LA. March 1991b.

Louisiana. Department of Natural Resources. *Comparative Risk Project: Quality of Life Cost Estimates*. Prepared by Stephen Farber, Department of Economics, Louisiana State University. Baton Rouge, LA. December 1990.

McClelland, G., W. Schultze, and B. Hurd. "The Effect of Risk Beliefs on Property Values: A Case Study of a Hazardous Waste Site." Unpublished. 1989.

Michaels, G., V.K. Smith, and D. Harrison. "Market Segmentation and Valuing Amenities With Hedonic Models: A Case Study of Hazardous Waste Sites." *Journal of Urban Economics*, vol. 28 (1990): 223-242.

Northeast Center for Comparative Risk (NCCR). Personal communication with Richard Minard. July 1992.

Oge, Marge. "Conversation with Marge Oge." *Mobility*, vol. 11, no. 6 (June 1990): 43-46.

Rice, D.P. "The Economic Costs of Illness: A Replication and Update." *Health Care Financing Review*, vol. 7, no. 1 (Nov. 1985): 61-80.

Seattle. Office of Long-Range Planning. *Environmental Risks in Seattle: A Comparative Assessment*, Seattle Environmental Priorities Project: A Report by the Technical Advisory

End Notes

[1] The dollar figures given in the remainder of this chapter are from different years. Analysts using the formulas presented should adjust values to a consistent dollar year. To do so, a price-deflator index, such as the Consumer Price Index, or more specific price indices for agricultural products, medical services, etc., may be used. Two sources of price-deflator tables are *The [annual] Economic Report of the President*, compiled by the Council of Economic Advisors, and *The Survey of Current Business* (July issues).

[2] If there are large variations in pollutant concentrations across the region, it may be preferable to estimate damages on a state-by-state basis and add the results.

[3] Consumer surplus and willingness to pay are synonymous in those instances where the "good" is free—e.g., the willingness to pay for a day of recreational fishing is the same as the consumer surplus (assuming there is no charge for fishing).

[4] EPA has estimated the background ozone level to be between 0.02 and 0.03 ppm.

[5] Non-use value describes a willingness to pay to improve a resource that the individual may not immediately plan to use. Several types of non-use value exist, including "option value" (willingness to pay to preserve the option of using the resource), "existence value" (willingness to pay to simply know that the quality of a resource is being preserved), "altruism" (knowing the resource is preserved for others' current use), and "bequest value" (knowing the resource is preserved for future generations' use).

[6] Other damages are possible (e.g., increased travel costs).

[7] The model used in the document (RIA) from which this equation is drawn has been reestimated to correct for a minor calculation error. This was done by EPA Region IV in a welfare effects study as a part of its comparative risk evaluation (EPA 1990e).

[8] The above model is not appropriate for measuring damages in areas with high-baseline visual ranges (i.e., greater than 90 km). The available models and contingent-valuation studies used to estimate this equation address visual ranges of up to only about 50 km. As a result, if existing visibility figures of over approximately 90 km are used in the equation, the estimated willingness to pay will be negative—an illogical result.

[9] The one-mile radius is typically applied because two of the three studies cited above frame the willingness-to-pay question in terms of miles from the site.

[10] Frequently, data are available on the total number of contaminated wells in a state or region. This figure must be divided by an estimate of the time frame over which the wells were contaminated to arrive at an estimate of the number of wells contaminated per year.

[11] The estimates of treatment costs in the documents from which these figures are drawn have been called into question and are under review.

[12] This is a very rough approximation of the potential change in UV-B radiation over time; the analyst should attempt to locate more precise information as it becomes available.

[13] The option illustrated here is based on the work done by Region I; a more detailed description can be found in *Unfinished Business in New England; A Comparative Assessment of Environmental Problems—Societal Costs Work Group Report*, April 1990.

U.S. EPA. Office of Ground Water and Drinking Water. *Regulatory Impact Analysis of Proposed National Primary Drinking Water Regulations for Synthetic Organic Chemicals.* March 1989c. Addendum, October 1990.

U.S. EPA. Office of Air and Radiation. "Regulatory Impact Analysis (RIA) on the National Ambient Air Quality Standards for Sulfur Oxides." Appendix A. Draft. Washington, D.C. March 1988a.

U.S. EPA. Office of Solid Waste. *Subtitle D Risk Model.* Appendix E. Washington, D.C. August 1988b.

U.S. EPA. Region III. Cross-Media Project: Welfare Damages Work Group. *Explanation of Ranking Process.* Philadelphia, PA. 1988c.

U.S. EPA. Office of Research and Development. *Radon Reduction Methods: A Homeowner's Guide.* Washington, D.C. September 1987.

U.S. EPA. Office of Air Quality Planning and Standards. *Comparative Risks for Primary Air Pollutants.* Vols. I and II. Draft Final Report. Washington, D.C. 1986a.

U.S. EPA. Office of Policy Analysis. *A Damage Function Assessment of Building Materials: The Impact of Acid Deposition.* Prepared by Horst et al. Washington, D.C. 1986b.

U.S. EPA. Office of Policy Analysis. *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis.* Washington, D.C. 1985a.

U.S. EPA. Office of Policy Analysis. *A Methodological Approach to an Economic Analysis of the Beneficial Outcomes of Water Quality Improvements from Sewage Treatment Plant Upgrading and Combined Sewer Overflows.* Washington, D.C. 1985b.

U.S. EPA. *Damage Cost Models for Pollution Effects on Material.* Prepared by E. McCarthy et al. Research Triangle Park, NC. 1983.

U.S. EPA. Office of Research and Development. *Air Quality Criteria for Oxides of Nitrogen.* Washington, D.C. 1982.

Vaughan, W.J., and C.S. Russell. "Valuing a Fishing Day: An Application of a Systematic Varying Parameter Model." *Land Economics,* vol. 58, no. 4 (Nov. 1982): 450-463.

Vermont. Agency of Natural Resources. *Environment 1991: Risks to Vermont and Vermonters.* Technical Appendix. Waterbury, VT. 1991.

Walsh, R.G., et al. *Review of Outdoor Recreation Economic Demand Studies With Non-Market Benefit Estimates.* Prepared for Colorado Water Resources Institute. Fort Collins, CO. 1988.

Committee. Seattle, WA. October 1991.

Smith, V.K., and W. H. Desvouges. "The Value of Avoiding a LULU: Hazardous Waste Disposal Sites." *The Review of Economics and Statistics*, vol. 63, no. 2 (May 1986): 293-299.

Teramura, A.H. "Overview of Our Current State of Knowledge of UV Effects on Plants." In *Effects of Changes in Stratospheric Ozone and Global Climate.* U.S. EPA/United Nations. Washington, D.C. 1986.

U.S. Environmental Protection Agency (U.S. EPA). Region IV. *FY92-96 Strategic Plan.* Atlanta, GA. 1992.

U.S. EPA. Region II. Office of Policy and Management. *Region II Risk Ranking Project, Economic/Welfare Damages from Pollution: Relative Ranking and Problem Analyses.* New York, NY. 1991a.

U.S. EPA. Drinking Water Research Division. Risk Reduction Engineering Laboratory. Personal communication. Cincinnati, OH. September 1991b.

U.S. EPA. Office of Policy, Planning and Evaluation. *Valuation of Forest Ecosystem Services: Estimating the Benefits of Controlling Climate Change.* Washington, D.C. September 1991c.

U.S. EPA. Office of Solid Waste. *Potential Benefits of Preventing Contamination of Wetlands Due to Releases from Hazardous Waste Facilities: Analysis of Selected Sites.* Washington, D.C. March 1991d.

U.S. EPA. Science Advisory Board. *Reducing Risks,* Appendix A: pp. 23, 26, 36. Report of the Ecology and Welfare Subcommittee. Washington, D.C. September 1990a.

U.S. EPA, Office of Air Quality Planning and Standards/U.S. National Park Service, Air Quality Management Division. *1990 Preservation Values for Visibility Protection at the National Parks.* Draft Final Report prepared by L.G. Chestnut and R.D. Rowe. Washington, D.C. February 1990b.

U.S. EPA. Office of Policy Analysis. *Ecosystem Services and Their Valuation.* Washington, D.C. February 1990c.

U.S. EPA Region I. *Unfinished Business in New England: A Comparative Assessment of Environmental Problems.* A Report of the Societal Costs Work Group. Boston, MA. April 1990d.

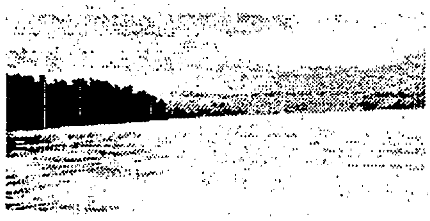
U.S. EPA. Region IV. Policy, Planning, and Evaluation Branch. *Comparative Risk Evaluation: Welfare Effects Study.* Atlanta, GA. 1990e.

U.S. EPA. Office of Air Quality Planning and Standards. "Review of National Ambient Air Quality Standard for Ozone: Assessment of Scientific and Technical Information." Table XI-1. Staff paper. Research Triangle Park, NC. June 1989a.

U.S. EPA. Office of Ground Water and Drinking Water. *Regulatory Impact Analysis: Benefits and Costs of Proposed National Primary Drinking Water Regulations for Inorganic Chemicals.* Washington, D.C. March 1989b. Addendum, October 1990.

Risk Management

EXHIBITS



3.1 Risk Management

certain exposures to lead in the environment. Therefore, in order to develop appropriate risk-reduction or -prevention strategies, it is important to understand which source seems to be contributing the most to the problem and what actions are currently being taken to address it.

Evaluating the effectiveness of existing programs is important in order to get a sense of whether a new program is needed or if the current program can meet the environmental goal. When considering shifting resources among programs, the *net* risk reduction of any actions that might be taken should be considered. This entails selecting the risk management approach that most effectively reduces or prevents risk. It is important to remember that some problems may pose lower risk because: (1) there is an effective control program in place that keeps the risks low, or (2) the problem area does not pose inherently high risks. To make this determination, it is necessary to know how well the control program is currently addressing risks, at what cost, and what changes in risk reduction and cost are likely to occur in the future. In the case of risks that are being effectively managed and would likely increase in the absence of such efforts, disinvesting resources from that program might result in a net *gain* of risk. However, in the case of a problem area posing relatively lower risks, there could be a case for deferring further investments until more serious risks are addressed.

In addition, if a comparative risk project is intended to identify emerging environmental threats in addition to existing risks, then the analysis must encompass anticipated changes or trends in risk. Risks can increase or decrease because of changes in technology, economic conditions, and/or demographic factors. Some of these issues may have been accounted for in the risk rankings. If they have not been accounted for, then a trend analysis can be accomplished in a relatively non-quantitative fashion using work group members' best professional judgment, or using a more rigorous quantitative approach involving modeling and other forecasting techniques. For example, agricultural forecasts may shed light on the need for certain non-point source water pollution controls and how quickly they will be needed to meet certain environmental goals.

Uncertainty is often very prominent in comparative risk projects. In some cases, the uncertainty surrounding a specific problem area is relatively small. However, in other cases, uncertainty can be quite large and have a profound effect upon the risk-ranking and priority-setting processes. When the uncertainty is large, it may be appropriate to focus on research strategies in order to better articulate and eventually better solve the problem. If significant risks are not likely to occur while research is being conducted on the problem, and the cost of the research is affordable, then research may be the most appropriate course of action to take. However, if the cost of the risk-reduction or -prevention strategies is low compared to the costs of research and possible adverse effects which might occur during this period, then it may be advantageous to take immediate action rather than spending the time and resources to gather better data. In many instances, it may be most appropriate to consider low-cost risk-reduction and -prevention strategies concurrently with research efforts.

Risk management is a decision-making process in which the ranking results from the risk assessment process are integrated with economic, technical, social, and political considerations to generate a prioritized set of risk-reduction or -prevention strategies that will achieve environmental goals. Whereas risk assessment asks how bad is the problem, risk management asks what can and should be done about it. The effectiveness of risk management strategies can be monitored and evaluated in terms of the progress made toward goals using environmental indicators, such as a reduction in the ambient concentration of a certain pollutant or an increase in the biological diversity of a given ecosystem.

Translating analysis into action represents the culmination or "payoff" of the comparative risk process. Despite the brevity of this chapter, it is important to note that as much thought and analysis should be given to selecting the most appropriate risk- reduction or -prevention strategies during the risk management process as is devoted to assessing and ranking problem areas during the risk assessment process. Ideally, the end result of this risk management process is a set of sound, long-term risk-reduction or -prevention strategies that will achieve broadly supported environmental goals in a cost-effective manner.

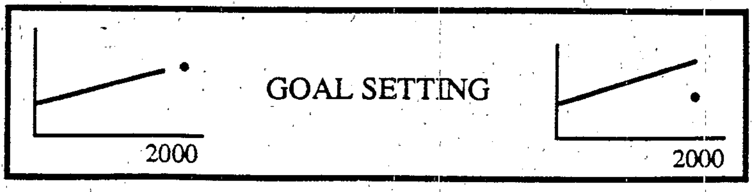
One of the most important aspects of risk management is the integration of the concerns and values of the public, other agencies, public interest groups, and the regulated community to set clear goals for the environment, specific criteria for evaluating strategies, and an open process for selecting risk management priorities to implement.

Prerequisites to Risk Management

Before launching the risk management phase of a comparative risk project, it is important to have several things in order. First, it is necessary to have a ranking of human health, ecological, and quality-of-life risks. Second, it is important to review the goals of the comparative risk project to ensure that the risk management phase is structured to meet the goals and to account for additional goals that may have developed since the project was started. Third, the risk management process should include participants from the risk analysis phase of the project and participants who can help to promote the implementation of selected risk management strategies.

The risk rankings are an important component of the risk management process. While the risk rankings do not in themselves represent an organization's priorities, they are an appropriate starting point for considering risk-reduction or -prevention strategies. To determine which strategies may work best, members of the risk management work group must understand the "anatomy of risk." That is, not only identifying which problems pose the highest risks, but understanding why they pose the highest risks and who is bearing those risks. It is important to understand which stressors are creating the most significant risks and which human populations and ecological receptors are at greatest risk, as well as the effectiveness of existing programs designed to address these risks. For example, high blood-lead levels in children can result from contaminated drinking water, lead paint, or lead dust deposited in soils. However, there may be programs already in place to address

Exhibit 3.1.2:
Monitoring Progress Toward Goals



Step 2: Identify Criteria for Evaluating Risk Management Strategies

Once a set of specific, measurable goals has been established, then it is necessary to establish risk reduction or prevention strategies to achieve these goals. Before selecting risk management strategies, it is necessary to first decide what criteria will be used to evaluate possible risk management strategies. Then, each proposed strategy can be evaluated against a common set of criteria to determine its feasibility and relative advantage compared to other strategies that might be employed. For instance, almost any risk management strategy will need to be technologically and economically feasible. Several criteria that have been consistently selected in past projects to evaluate these strategies are listed in Exhibit 3.1.3. The criteria presented here are merely guidelines; other criteria may be added or substituted, depending on the specific objectives of the project.

Exhibit 3.1.3:
Examples of Criteria for Evaluating Risk Management Strategies

- Risk reduction/prevention potential
- Statutory and regulatory authority
- Cost and cost-effectiveness
- Technical feasibility
- Speed/ease of implementation
- Environmental equity

Risk Reduction/Prevention Potential

Risk reduction refers to the amount of risk posed by an environmental problem that is estimated will be reduced by implementing a proposed strategy. Risk reduction presumes that an existing environmental problem poses risks. However, for some environmental strategies, it is the amount of risk prevented, as opposed to the amount or risk reduced, that is important to estimate in evaluating a proposed strategy. In terms of evaluating proposed strategies, risk reduction and risk prevention are equivalent.

Statutory and Regulatory Authority

There must be a legal basis for any risk management strategy that is implemented. This requires determining if the authority exists to implement proposed strategies. If authority exists, then it must be determined where it is located (e.g., with another agency or level of government) and how it can be most appropriately exercised. When statutory authorities impede risk reduction actions that an agency would like to take, project participants must

Risk Management Steps

Risk management can be done in a variety of ways, but there are a number of steps that have been consistently used in past and current comparative risk projects. The four steps outlined in Exhibit 3.1.1 represent one way to approach this process. These steps are not meant to be prescriptive, but they can be used as a general guide to the process. They are described in more detail later on in this section.

Exhibit 3.1.1:
Risk Management Steps

Step 1: Set Environmental Goals

Step 2: Identify Criteria for Evaluating Risk Management Strategies

Step 3: Propose and Analyze Strategies to Achieve Goals

Step 4: Select Strategies for Implementation and Monitor Results

Step 1: Set Environmental Goals

The development and use of measurable environmental goals can provide strategic direction for the long-term efforts needed to address environmental problems. The goal-development process—if it includes participation across a broad range of government agencies with environmental responsibilities, private stakeholders in environmental policy, and the public—is an opportunity to build consensus on environmental priorities. Once goals are set, they can provide some perspective on the kinds of strategies that are needed to address some of the high risks that have been articulated in the risk assessment phase of the project. Additionally, goals are a good starting point for thinking about ways that one can measure progress after management strategies have been selected. For example, if nutrient runoff from agricultural fertilizer use is a significant risk, then one possible goal might be to reduce nutrient levels by 50 percent within 10 years.

Exhibit 3.1.2 depicts two different scenarios of how monitoring goals can help managers determine whether they are successfully accomplishing their objectives. On the left-hand side of Exhibit 3.1.2, it appears that current efforts to meet the hypothetical goal are making satisfactory progress toward that goal. This goal might represent an increase in the number of stream miles which meet all federal and state standards/designated uses by the year 2000. The graphic on the right-hand side depicts a situation where progress toward the goal does not appear to be satisfactory. In fact, it appears that the trend is away from the goal that has been set. This may alert managers to the need for a review and possible change in the current strategy. As a general rule, goals should be important, measurable, understandable, and set within a certain time horizon.

developed now to improve our understanding of the sources, routes of exposure, and health effects on specific populations at higher risk, such as ethnic minorities or individuals in high-risk occupations or neighborhoods.

Step 3: Analyze Strategies to Achieve Environmental Goals

The purpose of this step is to generate and analyze risk management strategies through an iterative process that gradually focuses on the most effective means of achieving environmental goals. To start the process, work group members may propose risk reduction or prevention strategies from a "tool box" of risk management approaches. Proposed strategies can then be analyzed in terms of the criteria that have been selected by the work group to evaluate the merits of various strategies. The more promising strategies can then be subjected to more rigorous analysis until consensus is reached. By focusing the analysis of strategies on environmental goals, it is more likely that common links between different problems will be identified and simultaneously addressed.

It may be very helpful to begin this process by introducing work group members to a round-table discussion of various risk management approaches and how they work. For instance, managers have increasingly recognized that preventing pollution from occurring in the first place is generally preferable to control and abatement activities after the fact. Thus, pollution prevention has become a powerful risk management approach. Other examples of risk management approaches include:

- Scientific and technological measures
- Provision of information to the public
- Market incentives and disincentives
- Conventional regulations
- Effective and innovative enforcement
- Interagency and international cooperation

Pollution Prevention

One of the recommendations of the Science Advisory Board's (SAB's) Strategic Options Subcommittee was that pollution prevention "should consistently be the most important approach for reducing environmental risks over the long term" (EPA 1990). The subcommittee defined pollution prevention as:

> changes in raw materials, products or technologies of production which reduce the use of hazardous materials, energy, water, or other resources and/or the creation of pollutants or destructive results, without creating new risks of concern.

Pollution prevention can be implemented in a number of ways, such as market incentives, expanded community right-to-know programs, conventional regulations, and government procurement policies that promote pollution prevention. Many of the most promising pollution-prevention initiatives focus on strategies that address several problems simultaneously, such as toxics-use reduction, increased energy efficiency and conservation, or a comprehensive agricultural policy.

assess the possibility of changing them. This may require working cooperatively with other agencies, working with other levels of government, seeking new authorities or changes in existing authority from a state legislature, or encouraging the private sector to take voluntary actions to reduce or prevent risks. The state of Washington passed several new pieces of legislation as a result of conducting a comparative risk project.

Cost and Cost-Effectiveness

In evaluating risk management strategies, it is important to consider both the cost and cost-effectiveness of the option. The cost of an option can be analyzed in a number of ways. It might include the cost of the strategy to the state government, the cost to the private sector, and/or the cost to the general public either in terms of taxes or in substitution costs associated with behavioral changes.

Cost-effectiveness refers to the cost of implementing a risk reduction or prevention strategy relative to the amount of expected environmental improvement or risk reduction. In looking at both cost and cost-effectiveness, it is important to determine a time frame for calculating cost-effectiveness that is consistent with the goals associated with the strategy.

Technical Feasibility

The technical feasibility of risk management strategies must be considered and evaluated. Effective "off-the-shelf" technologies may be readily available for some environmental problems, but may not exist or may be prohibitively expensive for other environmental problems. In some cases, technological "fixes" may not be satisfactory or even possible. For instance, it is far more effective technically and financially to prevent ground-water contamination than to remediate contaminated ground-water supplies.

Speed/Ease of Implementation

There may be some strategies that are cost-effective and technically feasible, but which cannot be easily or quickly implemented. Some may require a multiyear effort before results can be seen. For example, an education program targeted toward public schools may take a long time to show results if the goal is to permanently change the public school curriculum. This doesn't mean that the strategy should not be pursued; rather, it means that expectations should be realistic when making public commitments of this nature. It may also be advisable to combine some strategies offering short-term results with other strategies with longer time frames before results can reasonably be expected. Enforceability is another aspect of implementation that is very important, relating to the feasibility and ease of obtaining private firms' compliance with the strategy.

Environmental Equity

Specific populations can be at higher risk because they are systematically exposed to higher levels of harmful materials (e.g., migrant farm workers) or because they are more susceptible to developing health effects (e.g., poor urban women who have limited access to health care services). Risk management strategies can be designed to explicitly address environmental-equity concerns. The ability to select risk management strategies that address equity concerns is greatly enhanced by analyzing the risk burden on specific populations during the risk analysis phase of a comparative risk project. Methods are being the most efficient means of reducing pollution in order to reduce their costs. It is increasingly accepted that market-oriented risk management approaches are needed in the future to achieve the socially optimal level of environmental protection in a cost-effective way.

Economic incentives can be divided into five categories. They are:

- *Creation of Markets*—The creation of tradable government-issued marketable permits to discharge or emit pollutants or use scarce environmental resources. An amount of pollution caused by an activity is established by legislation and then the right to conduct that activity is allotted among firms in the form of permits. A prominent example of this is the "bubble" policy for certain air pollutants (i.e., sulfuric and nitric precursors to acid rain) in specific areas. Firms that can more easily reduce the amount of pollutants they emit below the allowable level have the right to sell or trade their surplus "shares" to other firms. They may also "bank" the extra "shares" for use in future years. On the other hand, firms with high pollution control costs will have an incentive to buy permits rather than invest in more expensive control technologies. Over time, the level of pollution or "ceiling" is lowered to achieve healthier levels of environmental protection. Government policies can also be used to reduce barriers to market entry.
- *Monetary Incentives*—"Pollution charges" designed to change market incentives, such as providing or eliminating environmentally damaging government subsidies. These can take the form of user fees that have the principal motivation of revenue generation, or taxes that are viewed as transitional instruments and revenue-neutral. In theory, fees and taxes will reduce pollution up to the point where the marginal costs of control equals the amount of the fee or tax. They may also be used in conjunction with other regulatory controls.
- *Deposit-Refund Systems*—Government policies to discourage the disposal of natural resources by encouraging central collection efforts for their reuse. A surcharge is levied on an item (e.g., a beverage container) at the time of purchase. The surcharge is refunded when the item is returned after use.
- *Procurement Policies*—The public sector uses its own buying power to stimulate the development of markets, such as policies designed to encourage recycling and discourage preferential treatment of products made from virgin materials. Such policies can be applied to a broad range of products.
- *Revision of Legal Standards*—Prescribing liability for damages from polluting activities can provide a very powerful incentive to change current practices. Liability can be joint, strict, several, and retroactive. Numerous other attributes of liability can be adjusted in support of environmental goals, such as changing the burden of proof, limiting damage awards, standing to sue, and allocating responsibility among the responsible parties. However, this tool should be used cautiously as litigation carries very high, socially unproductive transaction costs.

Scientific and Technological Measures

Scientific and technological measures can be divided into two categories: (1) research and development activities to improve the scientific understanding of problems, and (2) innovations in pollution-prevention approaches and pollution-control technologies.

Research and development (R&D) studies are undertaken to increase our understanding and knowledge of environmental problems and the effectiveness of remedial and pollution-control techniques. The facts, insights, principles, and technological advances gained from such activities are very useful to those considering ways to control, reduce, or prevent risks. However, risk managers and decision makers must be informed of the latest developments in a wide range of fields so that this information can be incorporated into the decision-making process. One of the major findings of the Report of the Expert Panel on the Role of Science at EPA, *Safeguarding the Future: Credible Science, Credible Decisions,* is that "appropriate science advice and information is not considered early or often enough in the decision-making process" (EPA 1992c). Thus, it is very important that risk management team members who are familiar with the latest scientific and technological advances share this information with the other work group members.

Public Education/Outreach

Information can be provided to consumers and producers of products and services that can affect personal choices and consumer preferences. "Green labeling" and consumer guides can help consumers reduce their own risks (e.g., information about radon), reduce damages to their community or to society (e.g., community right-to-know and information on toxic waste disposal). Technical training and technology transfer can be used to inform people and firms of cost-effective means of preventing or controlling pollution. Environmental audits can be used to observe operations at plants and suggest ways of preventing or controlling emissions. These means of providing information to the public can and should be used in a coordinated fashion to achieve environmental goals.

Market Incentives

The most direct way to convey information to consumers and producers about the adverse impacts of certain activities or products is to include the externalized costs of those impacts in the prices of their activities or products. Because effective markets do not exist for many natural resources, such as breathable air or clean rivers, there exists no financial incentive for firms or individuals who pollute the environment to change their behavior. Society ends up paying for these "negative externalities" in terms of increased health care costs or environmental cleanup programs. The SAB noted in its report, *Reducing Risk,* that "government policies should be designed to encourage the socially optimal amount of environmental protection by ensuring that consumers and producers face the full costs of their decisions - not just their private costs, but the full social costs and consequences of their actions" (EPA 1990).

Market mechanisms can alter the behavior of polluters by changing the costs they face of continuing their present practices or behaviors. Unlike regulations, incentive-based policies influence rather than dictate the actions of individuals and firms, and allow them to find

- A public policy study sponsored by ex-senators Tim Wirth and John Heinz. *Project 88: Harnessing Market Forces to Protect Our Environment.* Washington, D.C. October 1988.

Step 4: Select Implementation Strategies and Monitor Results

In this step of the process, risk management strategies are evaluated using the criteria that have been developed. Implementation strategies are developed for selected strategies that include goals and ways to measure progress toward those goals. Following an initial analysis of proposed risk management strategies, the work group will probably have narrowed the field of strategies down to a manageable number of the most promising to consider for implementation.

More refined analytic approaches can be used as the evaluation process moves closer to the decision-making point, such as assigning numerical values (e.g., four- or five-point scales), semi-quantitative values (e.g., high, medium, or low scores), or non-quantitative descriptions to proposed strategies. In addition, weights can be added to different criteria to account for their importance relative to one another. However, extremely detailed weighting schemes and mechanistic formulas are not recommended since they are unlikely to prove satisfactory to work group members and may not be easily communicated to a broader audience. On the other hand, non-quantitative approaches tend to be less structured and rigid, allowing participants to bring more of their values and judgments to bear on the selection decisions through a process of group debate and discussion.

Structuring the decision-making process in a way that maximizes its integrity and relevance is crucial to the likelihood that the work group's decisions will actually be carried out. A vigorous and open discussion of the relative advantages and disadvantages of strategies among a diverse and knowledgeable work group will lend integrity to the process. The process will more likely be relevant and credible to those who have the ultimate authority to implement the strategies if it has included the right people, used appropriate criteria, and been reported clearly and persuasively.

Once risk management strategies are selected, then they must be implemented and monitored over time to ensure that environmental conditions are changing in the direction of the environmental goals that have been established. The risk management work group should be prepared to present well-defined and credible strategies that will achieve broadly supported goals in a way that meets the public's interests and needs. Implementation is more likely to succeed if the strategies are part of an overall strategic plan that firmly ties environmental policies to budgets and meaningful, measurable results. Monitoring the actual results of the strategies will help environmental managers and the public know if their efforts are working or if they need to be adjusted and revised.

The risk management process can help environmental managers identify the most promising risk-reduction or -prevention opportunities, develop clear environmental goals and strategies to achieve them, build public and political support for their programs and policies, and focus on those measures of environmental quality that are most relevant to

Conventional "Command-and-Control" Regulations

Over the past two decades, substantial resources at all levels of government have been spent developing, administering, and enforcing traditional "command-and-control" regulations that typically require large pollution sources to install engineering systems to reduce pollutant discharges or emissions to the environment. This approach has resulted in significant environmental gains, such as improved water quality due to massive investments in waste-water treatment plants. In contrast, the nature of many of the most significant remaining problems makes them less amenable to command-and-control management approaches. However, that does not mean that these kinds of requirements are never appropriate. For example, standards can be very effective in forcing technology development for pollution-prevention processes in new or retrofitted facilities.

Effective and Innovative Enforcement

If a firm or an individual perceives that the expected value of criminal penalties is less than the additional cost of installing pollution-control equipment or changing production processes, then they may decide that it is in their best economic interests to violate their permit. The disincentives to violating the permit are the amount of the penalty *and* the likelihood of getting caught as well as possible negative public reaction. Innovative enforcement strategies include citizen suits, multimedia approaches to site inspections, and environmental audits. For instance, by cross-referencing poor corporate behavior across media, state and federal environmental enforcement officers have been able to build stronger cases against corporate "bad actors."

Interagency and International Cooperation

The interdisciplinary nature of comparative risk projects makes them ideal forums for developing and implementing risk management strategies beyond the scope of any single agency or level of government. In many cases, the policies and activities of other governmental and private organizations in the energy, transportation, housing, development, agriculture, and taxation fields have contributed significantly to many environmental problems. Therefore, the cooperation and participation of agencies from a number of different sectors is important in finding lasting and comprehensive solutions to these problems.

In addition, many environmental threats are now on a global scale, such as climate change, ozone depletion, habitat destruction and degradation, and loss of species and biodiversity. These kinds of transboundary threats cannot be adequately addressed by any nation's individual efforts; they must be addressed within a multinational context. A more full treatment of all of these risk management approaches can be found in the following documents:

- U.S. EPA. Office of Policy, Planning, and Evaluation. *Economic Incentives: Options for Environmental Protection.* (21P-2001) March 1991.
- U.S. EPA. Science Advisory Board. *Relative Risk Reduction Project, Appendix C: Report of the Strategic Options Subcommittee.* (EPA SAB-EC-90-021C) September 1990.
- OECD. *Economic Instruments for Environmental Protection.* Paris, France. 1989.

REFERENCES

National Commission on the Environment. *Choosing a Sustainable Future.* Island Press, Washington, D.C. January 1993.

U.S. Agency for International Development. Bureau for Latin America and the Caribbean. *Environment Strategy for Latin America and the Caribbean.* Washington, D.C. January 1993.

U.S. Environmental Protection Agency (U.S. EPA). Office of Policy, Planning and Evaluation. *An Overview of Risk-Based Priority Setting at EPA.* Washington, D.C. November 1992a.

U.S. EPA. Office of Policy, Planning and Evaluation. *Preserving Our Future Today: Strategies and Framework.* Washington, D.C. September 1992b.

U.S. EPA. Science Advisory Board. *Safeguarding the Future: Credible Science, Credible Decisions.* Report of the Expert Panel on the Role of Science at EPA. Washington, D.C. March 1992c.

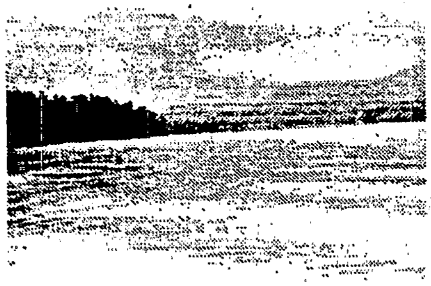
U.S. EPA. Science Advisory Board. *Reducing Risk: Setting Priorities and Strategies for Environmental Protection.* Report of the Strategic Options Subcommittee: Relative Risk Reduction Project. Washington, D.C. September 1990.

monitoring the impact of those programs and policies on the environment. Due to the fact that there are more environmental problems to be addressed than resources allow, the risk management process can help environmental managers make choices and set priorities.

Special Applications

TABLES

EXHIBITS



4.1 International Application of the Comparative Risk Methodology

- In the risk analysis phase, risks to human health, damages to ecosystems, and adverse economic and social impacts are assessed and their relative risks are ranked.
- In the risk management phase, environmental priorities are established based on risk and non-risk factors. Environmental priorities can differ from the risk ranking due to such non-risk factors as cost-effectiveness, technical feasibility, public perception, and available resources.

Major Differences for International Comparative Risk Projects

The general concepts presented in this document are appropriate to all applications of comparative risk analysis. Some important differences may exist in studies conducted in other countries that could influence the design and implementation of the study, such as:

- Different problem areas—For example, desertification and microbial disease.
- Different criteria for problem areas—For example, impacts on traditional life styles and economies.
- Varied range and type of data sources, with international sources perhaps playing a greater role.
- Different analytical methods because of differences in problem areas, available data, and available technical expertise.
- Different audiences, such as international development agencies.
- Different participating organizations because of the institutional setting.

Because of all these potential differences, this section addresses organizational, design, and methodological issues that are specific to comparative risk studies outside the United States. Countries similar to the United States in both function and type of environmental problems can follow the main text of this guidebook; those nations that are different can use this section as a rough guide (see Exhibit 4.1.1). The section is aimed at an audience of potential project coordinators in both industrialized and non-industrialized nations, as well as senior environmental policy makers with some interest in the details of comparative risk analysis. Given the focus on differences, this section should not substitute for a careful reading of other sections of the document.

Comparative risk represents a set of tools that can be used to address different environmental problems, but not all the tools are needed for every application, and new tools may needed for specific studies. Resolution of these issues is an iterative process, requiring adjustment throughout the study. As discussed in Section 1.2, a successful comparative risk project will coordinate the original project design and objectives with the resources and time available to complete the effort. This requires careful attention in the early stages of a project to the consistency between objectives and resources, process and structure, and responsibilities and tasks. During the risk analysis phase of a project, the focus is on the systematic analysis and ranking of a number of environmental problem areas. Subsequently, the risk management phase of a comparative risk project is the process by

In many countries, poor environmental conditions pose human health risks, damage ecological systems, and have adverse economic and social impacts. These countries often have limited resources to address these problems. In such situations, it is essential that governments establish environmental priorities and wisely invest available resources by seeking the greatest risk reduction or prevention opportunities possible. To make such decisions, information on the relative human health, ecological, and quality-of-life impacts posed by various environmental problems is necessary.

Comparative risk helps organizations evaluate environmental problems for a given geographic area and determine their relative risks. Subsequently, environmental priorities can be set and integrated with social and economic policies. This process may be of particular interest to countries undergoing substantial economic development or change.

Comparative risk may enhance environmental decisions that many countries are facing by:

- Building technical capabilities to collect and analyze environmental data and apply analytical results to addressing environmental concerns.
- Building managerial capabilities, within and among environmental organizations, to better address environmental problems.
- Educating the public about environmental issues.
- Building capacity for public participation in the environmental decision-making process.
- Identifying environmental research and data-collection priorities.
- Justifying requests for international environmental assistance.
- Determining risk management priorities for individual pollutant sources.
- Allocating human and financial resources to effectively manage environmental problems.
- Building institutional capabilities for environmental protection.
- Designing legislative and regulatory frameworks for controlling environmental pollution.
- Serving as the critical component of a Country Environmental Study linking the profiling function of environmental problems to an Environmental Action Plan.

For example, industrialized nations in Central Europe may derive significant insights into the merits of investing in environmental improvements during industrial restructuring and the shift to a market economy. On the other hand, many non-industrial nations are facing the question of how environmental protection fits into economic-development initiatives. Comparative risk studies can help nations integrate economic-development and environmental-protection considerations.

In a broad sense, the comparative risk process is composed of two steps:

which the risk rankings are considered along with other non-risk criteria, such as cost-effectiveness, technical feasibility, and statutory authority, to develop risk reduction or prevention strategies to achieve environmental goals and set priorities for action.

Exhibit 4.1.1:
Sections of International Chapter

The remainder of this section includes five subsections that parallel the other sections of this document:

Section 4		**Section in Document**
Project Planning & Start-up	→	1.2: Creating a Strong Foundation
General Analytical Issues	→	2.1: General Analytical Issues
Risk Analyses Methods Data Sources & Collection	→	2.2: Human Health 2.3: Ecological 2.4: Quality of Life
Risk Management	→	3.1: Risk Management

Project Planning and Start-up

Once the objectives for a project are identified, then a work plan outlining roles, responsibilities, activities, and milestones should be developed to describe the project to potential clients or stakeholders. Suggested steps in the project planning and start-up phase include:

- Selecting a project director and support staff
- Assembling a project public advisory and steering committee
- Securing the support of key stakeholders
- Defining project goals and objectives
- Determining the role of public participation
- Determining the project's organizational structure
- Selecting technical work group members
- Identifying the list of problem areas to analyzed
- Setting time frame, milestones, and key technical work group tasks

Four major areas where studies in other countries differ from U.S. studies during the project planning and start-up phase are: (1) objectives and resources, (2) process design and organization, (3) participant selection and responsibilities, and (4) major tasks.

Objectives and Resources

Two of the first steps in the comparative risk process are to clearly define the goals and objectives of the study and to evaluate the consistency between the goals for the project and the resources allocated for it. The key question in defining the goals and objectives for the project is: How will the results be used? That is, will the study be designed primarily to allocate environmental resources within the country, to restructure environmental regulatory or legal authorities, to justify loans or grants from international or bilateral donor organizations, to train environmental managers in risk assessment techniques, to mobilize public support for environmental programs, to foster cooperation among different agencies or institutions responsible for environmental management, or to achieve some other purpose?

Defining objectives is an iterative process. Revising the fundamental objectives may be necessary if the data, resources, or time available are not sufficient to support the objectives as originally defined. Any part of a study could exhaust a substantial portion of the budget without significant benefits. In some cases, funds may be spent on consultants. External use of funds should be directed toward areas where technical analytical capabilities are weak, or where the contribution will make a significant impact on the results of the analysis. For example, a comprehensive study may not be needed if the primary study objective is to roughly reallocate environmental management resources based on risk or risk-reduction opportunities, while a more extensive study may be needed if the intent is to leverage investment from one or more aid agencies.

Some of these considerations, which could be substantially different from concerns in U.S. studies, are:

- *Major Goals.* What is supposed to happen as a result of the project?
- *Audience.* Does the primary audience for the study include local, regional, or national environmental officials; the general public; economic development interests; and/or international donor organizations?
- *Level of Analysis Required.* Given the proposed use of the study results, is a rapid, relatively low-cost screening assessment adequate, or is a more comprehensive analytical effort needed?
- *Data Availability.* Are the data available to adequately analyze problem areas given the proposed objectives and goals of the project?
- *Resources Available.* Are there sufficient financial and human resources, and time available to complete the proposed study?
- *Time Sensitivity.* Are there time-sensitive decisions that can use the results of the analysis?
- *Scope of Environmental Problems.* Does the project address both modern and traditional environmental problems? Both "brown" and "green" problems?

- *Linkages to Other Social and Economic Issues.* Environmental problems cannot be successfully managed if their solutions are sought in a vacuum from the other social and economic conditions and policies which affect how people live and use the environment. Are these links addressed and are the right people participating in the project who can affect or influence those other policy areas?

Process Design and Organization

Once the objectives are defined, project organizers must structure the comparative risk process and the responsibilities and functions of participants. This involves a variety of different considerations. The actual organization of functions should be linked closely with the project's overall objectives, and organizational structures should not be adopted without careful consideration of their usefulness for achieving specific project goals. The project's design and institutional structure should reflect generally accepted practices within the nation or the region. The lead agency coordinating the project must have the bureaucratic skill, technical expertise, and prestige to manage the project and act as an advocate for implementation.

In some cases, project organizers should add other functions to the project's structure. For example, a key objective of a comparative risk study currently being conducted in the northern Silesia region of Czechoslovakia and Poland is to identify not only the opportunities for greatest risk reduction, but also methods to pay for these reductions. As a result, along with the ecological, human health, and quality-of-life work groups, a financing work group has been established to identify and evaluate various revenue-raising mechanisms for funding environmental improvements. Another objective in the Silesia project is to institutionalize environmental discussions between Czechs and Poles. To accomplish this, a transboundary council was established to coordinate the activities of the steering committees and work groups in both countries.

In other cases, functions considered necessary in U.S. projects may not be as important in other countries. For example, if the major project objective is to forward requests to international organizations for loans or grants to pay for environmental improvements or to build the institutional strength of local environmental organizations, then it may not be as important to analyze the financial costs of the project and the availability of public funds to pay for it.

Participant Selection and Responsibilities

As depicted in Table 4.1.1, the project can be organized around four functional groups: the project manager, the steering committee, the public advisory committee, and the technical work groups. Their responsibilities can include some of the following areas:

**Table 4.1.1:
Project Participants and Responsibilities**

Organizational Units	Responsibilities
Project Manager	Supervises all aspects of the project
Steering Committee	Provides overall direction of the project
Public Advisory Committee	Ensures public participation in the process, and ensures the project's work remains understandable, relevant, and credible to the public
Technical Work Groups	Perform data collection, data analysis, and preliminary rankings

The project manager and support staff are charged with the day-to-day management of the effort. They are typically responsible for maintaining the overall intellectual consistency and quality of the technical analysis, motivating committees and clarifying their choices and responsibilities, and selecting and directing consultants. They are also responsible for ensuring that any necessary training is provided for project participants, including risk assessment, risk communication, and introduction to comparative risk training. They are heavily involved in "spreading the word" about the project. This may involve talking to the press and local civic and community groups, giving speeches, and writing articles. The project manager typically needs a variety of skills, such as good written and oral communication skills, a thorough understanding of the political environment, and a high level of enthusiasm and energy for the project.

The steering committee provides guidance on major project policies and ground rules, and represents the interests of the broader public. It may also be involved in setting the goals and objectives for the project, and approving the final rankings and priority actions. The public advisory committee is the key liaison between the government participants and the general public and major interest groups. It provides a forum for the essential two-way communication about risk and public values between these groups. In some projects, these two committees and their responsibilities are merged into one committee.

During the risk analysis phase of comparative risk, the technical work groups collect data; analyze the risks to health, ecology, and quality of life; and typically perform a preliminary risk ranking. In the risk management phase of the process, the work groups may work with members from other committees to develop and analyze a broad variety of strategies to prevent or reduce risks from these environmental problems.

Participants involved in international comparative risk projects are likely to be different from those described for U.S. projects in Section 1.2, especially if different objectives or functions have been defined. A recent study in Poland identified a wide spectrum of national and local agencies that had an integral role in the region's environmental protection, as depicted in Exhibit 4.1.2 (UNDP 1991).

Exhibit 4.1.2:
Key Environmental Participants: Katowice, Poland

Central Government

Ministry of Environmental Protection, Natural Resources and Forestry
Ministry of Health and Social Welfare
Ministry of Land Economy and Building
Ministry of Industry
Ministry of Agriculture and Food Economy
Ministry of Transportation and Marine Economy
Ministry of Ownership Transformations
Ministry of Labor and Social Policy
Central Planning Office
State Agency for Coal
Agency for Agricultural Marketing
Agency for Foreign Investments

Non-governmental

Nearly 2,000 registered organizations that deal with the environment

Regional Authorities

Department of Ecology
Department of Regional Policy
Department of Public Ventures
Department of Health
Department of Architecture and Scenic Views
Department of Geodesy

Local Government

Health and Environment
Local Ventures
Municipal and Housing Economy
Architecture, City Planning and Building Supervision
Geodesy and Land Management
Economic Activity
Communications and Transportation

Source: Borkiewicz, Jerzy et al. *Environmental Profile of Katowice*; Draft. UNDP/UNCHS/IBRD Urban Management Program. August 1991.

Project organizers should identify and recruit representatives from public interest and policy advisory groups. If achieving a national consensus on the need for environmental improvements is one objective of the study, then the steering committee should include key opinion leaders from the community, non-governmental organizations, universities, political figures, and the business community. Local or regional studies should rely heavily on people from the affected municipality, as they are likely to have the data, understanding, and ability to address the problems. If mobilizing international assistance is the goal, then including representatives of international organizations would be helpful to obtain their support of the study results. Furthermore, it is particularly important to have consistent and committed political and public support for the effort and to involve all potential stakeholders in the process. In the past, some environmental plans have failed because they neglected to consider the broader scope of stakeholders affected by environmental policy decisions.

From a technical perspective, the project almost certainly will require support from organizations and agencies that have not participated in environmental studies before. Selection of technical staff should be driven by the set of environmental problems under consideration and knowledge of the institutions and experts familiar with these problems. Such experts may be affiliated with government institutes or agencies, university research programs, non-governmental organizations, or industry. For example, if basic sanitation is defined as an environmental problem, a health effects work group might include experts on communicable diseases. Similarly, experts on the economics of rain forest harvesting might participate in a social and economic damages work group if rain forest damage is an important environmental problem.

Major Tasks

Project planning and start-up also requires defining the major tasks to be accomplished. Such tasks might include defining the risk analyses for human health, ecological, and quality-of-life impacts; the risk management process; and the risk communication strategy. A procedural task that project organizers might designate in the project start-up phase is the establishment of an institutional mechanism for coordinating data-collection efforts. For example, other agencies inside the government, non-governmental organizations, and foreign or international organizations, such as the U.S. EPA or the World Bank, collect information that can be of use to a project. Early identification and coordination of data collection can save a great deal of time and effort.

An example of the type of legitimate technical task that has not been particularly relevant in the risk management phase of U.S. studies is found in Central Europe. A key issue is whether enterprises that are large polluters will survive privatization and restructuring of the economy. To avoid recommending environmental investments in firms that may close as a result of economic changes, a key task of risk management might be an economic-viability analysis of financially troubled enterprises.

General Analytical Issues

This section highlights important differences between the analytical methods used in comparative risk studies in the United States and those used in other countries. The analytical methods used in projects in the United States are discussed in Sections 2.2 through 2.4 of this document. Other overarching analytical issues, such as the time frame and geographic scope of comparative risk projects, are addressed below. Further information on these analytical issues can be found in Section 2.1.

Time Frame Used for the Analysis

As discussed in Section 2.1 (General Analytical Issues), the time frame for the analysis should depend on the study's objectives. In certain applications, project organizers should place increased emphasis on future risks. Trends in rates of population, land use, and natural-resource depletion may be so severe that the scale and impact of a given environmental problem will be vastly different from the current risk it poses. This may be particularly important in countries where problems are rapidly getting worse. An analysis of future conditions may be necessary because the lack of environmental controls and resources limits current actions that might be taken to remedy the problem.

Projects that employ pollution-prevention techniques may wish to estimate future risks so that strategies can be developed to offset them. For example, land-use trends that destroy valuable habitats, such as rain forests or agricultural land, may have increasingly serious and irreversible future impacts on ecosystems and the global environment. Such impacts will have subsequent human health, economic, and social ramifications that can be factored into the analysis by projecting future effects.

Geographic Scope of the Analysis

One of the first issues to address in a comparative risk project is to define the geographic scope of the study. While most studies are national, regional, or local in scope, the project area can focus on coastal zones, watersheds and airsheds, national parks, or even specific population groups.

Defining the geographic boundaries of the study area also includes determining how to account for pollution entering the project area's boundaries from external sources as well as pollution generated within the project area that causes risk to other people and ecosystems outside the project area. It is useful to analyze and document these types of transboundary effects because this information can assist in selecting the most effective and equitable risk management strategies. If such issues are anticipated by project organizers, they can design the comparative risk process to include a transboundary analysis with representation from all affected countries or regions within a single country.

It may be worthwhile to consider global environmental issues, such as acid precipitation, global warming, and stratospheric ozone depletion. Spatially, such problems are global in terms of their sources and impacts. Some regions may be only minor contributors to these problems and may not wish to spend their resources on analyzing the problem. Others may face severe impacts from these problems, but may be unable to address them because the sources are not within their sphere of influence. However, it may be worthwhile to consider these issues because of the reality of global interdependence, and the need to highlight the magnitude of the threat.

Underlying Driving Forces

In many undeveloped and developing countries, critical environmental problems cannot be solved without also addressing other economic and social issues, such as rapid population growth, unsustainable patterns of natural-resource consumption, and inequitable social and economic conditions. Environmental degradation is a significant and growing threat to development throughout the world, and the nexus between deteriorating economic and environmental conditions is experienced most acutely by poor families in developing countries. Underlying many environmental problems are human activities that are the ultimate source of pollution and natural-resource degradation.

Because of its broad underlying scope, the impact of population growth should be considered in the analysis in a general fashion and not as a specific problem area. Rapid population growth creates ever-increasing demands on the environment in terms of the need for food, shelter, warmth, and medical, educational, and waste treatment services. For example, the linkage between projected economic and population growth and the already limited supply of energy produces a complex matrix of dependency, use, and impact. Project participants are likely to realize, if they do not already, that all their efforts to address specific environmental problems will be overwhelmed by these underlying driving forces unless actions are taken to address them simultaneously.

Developing a List of Problem Areas and Definitions

An important substantive difference among comparative risk studies in different countries is likely to be the need to emphasize different problem areas and use different criteria from U.S. projects to evaluate the impacts of these problems.

Section 2.1 (General Analytical Issues) provides information on alternative approaches for defining problem areas, including by source type, media, pollutant, and the organizational structure of existing environmental programs, among others. Section 2.1 also specifies general criteria to apply in developing a problem area list. However, this problem list was developed to reflect environmental concerns in the United States and should be carefully considered for its relevance to international studies.

The various approaches to defining problem areas are not mutually exclusive. To highlight particularly important issues, it may be appropriate to define some problem areas according to media and control programs and others according to specific pollutants or health effects. For example, a study conducted in Bangkok, Thailand, generally preferred defining problem areas in ways related to existing environmental control programs, but found that a few pollutants (e.g., lead) involved sufficient health risks to warrant separate consideration (AID 1990). The Silesia project's list is reflective of the environmental problems that have developed in that region as an outgrowth of expansive industrial economic policies (EPA 1992). Both the Bangkok and Silesia projects' lists are included in Exhibit 4.1.3.

In defining problem areas, the range of effects (i.e., risks to human health, the environment, and society's quality of life) posed by different problem areas should be carefully reviewed. Along with the typical effects analyzed, project organizers may wish to consider a broader range of social and cultural effects not commonly considered in U.S. studies. For example, developing nations face a broad range of public health problems directly linked to inadequate sanitary conditions. As a result, traditional environmental problems may need to be included in the analysis. It is also important to consider impacts caused by the underground economy. Illegal mining, poaching, and squatters, for example, have been shown to pose great risks to ecosystems. If these activities are linked to a specific problem area, then they should be included in the problem area definition and risk estimates.

The remainder of this section highlights four broad categories of problem areas and effects that have not received much attention in U.S. studies, but which may be very important in other countries. These categories should not be considered exhaustive, as some important problems are excluded. They are simply used as an organizational aid.

Agricultural Impacts

The environmental impacts of agriculture may be very important in countries that are highly dependent on this sector of the economy. In these countries, the consequences of environmental degradation may be extreme, and specific agricultural problems may merit special consideration. These problems include monoculture, desertification, salinization, depletion of soil resources or nutrients, overapplication of pesticides, or loss of arable land to urbanization.

Exhibit 4.1.3:
Problem-Area Lists for Bangkok and Silesia Projects

Bangkok Study	Silesia Study
• Air pollution - Criteria air pollutants: particulate matter, carbon monoxide, sulfur dioxide, ozone, nitrogen oxides (lead covered separately, in all media) - Toxic chemicals • Water pollution - Contamination of surface water -- Effects on drinking water -- Effects via direct contact, fish consumption, irrigation - Contamination of ground water - Drinking-water treatment • Food contamination (pesticides and metals) • Solid and hazardous waste disposal • Lead and other metals • Microbial disease (can relate to water supply, human and solid waste disposal, etc.) Source: U.S. Agency of International Development. Office of Housing and Urban Programs. *Ranking Environmental Risks in Bangkok, Thailand.* December 1990.	• Drinking-water contamination • Food contamination • Communal and hazardous waste • Surface water pollution • Air pollution • Occupational exposure

Addressing these problems may require using a variety of additional direct measures of effects, such as measuring species lost due to monoculture, area desertified, hectares lost to salinization, or soil/nutrient depletion. These measures, in turn, may need to be translated into estimates of health, ecological, economic, and social impacts. An example of this is the effect of urban migration on traditional cultures due to unsustainable agricultural practices.

Extraction of Natural Resources

Similar to agriculture, countries that are highly dependent on natural resources might develop a problem area list emphasizing the impacts of extracting specific natural resources. Issues that might merit consideration include the overharvesting of fuel wood, depletion of fisheries, destruction of rain forests, mining effects such as subsidence, and poaching of rare or threatened animals or plants.

Direct measures of these problems would need to be established, as well as an approach for determining their effects on human health, the environment, and society's quality of life. For example, overharvesting of fuel wood might be described in terms of hectares damaged per year. This damage estimate could then be translated into economic losses by determining the incremental cost of replacement fuel, loss of sustainable harvestable crops, and lost recreational opportunities. The social impacts could be estimated by determining the resulting increase in urban migration and the loss of sacred lands and traditional practices. The ecological effects from the overharvesting of fuel wood might include increased soil erosion, sedimentation of streams, decreased biodiversity, and the loss of aquatic and terrestrial habitats.

Urbanization Issues

Environmental problems associated with stresses from urbanization on both urban and rural settlements vary greatly, depending on geographic and economic conditions. Pressures imposed on the environment by population growth in urban or rural areas include the impacts of human waste disposal, as well as the degradation of ecosystems or loss of natural habitats from outward sprawl of population centers. Urban areas are of great concern because of the coexistence and scale of impact of both traditional and modern environmental problems. Urban migration places stress on infrastructure, depletes the natural resource base, and increases social stress.

In U.S. studies, problem areas associated with waste disposal are typically well defined, such as municipal landfills and sewage treatment plants. However, this approach may not be appropriate in some countries, and it may be necessary to consider alternative problem definitions, such as human waste, food wastes, or pollution of drinking water supplies. Direct measures for assessing the impacts of such problem areas would also be needed. For example, if inadequate human waste disposal is a major cause of microbial diseases, then the incidence of related diseases should be estimated. Similarly, infant mortality from waterborne disease (e.g., diarrhea and subsequent dehydration) might be a major consideration, if human waste disposal directly affects water supplies. In some cases, it may be necessary to start with incidence data and work backwards toward the sources.

Industrial Pollution

The degree and types of industrialization in a study area will be an important consideration in determining how industrial problems will be included in the problem area list. Industrial activity consists of the practices and processes used for manufacturing goods and services, including energy use. In some instances, project organizers may define specific industrial sectors as separate problem areas, particularly if only a few significant industries exist. For example, if production of coke from coal is a major polluting industry, a problem area defined as "air toxics from coke ovens" might be considered. In nations where cottage industries are a significant part of the industrial base, they might be assessed as small sources of pollution.

Project organizers might also focus on particular industrial pollutants of concern, such as contributions of atmospheric sulfates from neighboring countries. In addition, a lack of environmental standards in the work place might require detailed definitions of occupational exposures and risks associated with specific occupations. Development of problem area lists for industrial pollution may also require alternative approaches to measuring effects. For example, high levels of occupational disease might call for greater emphasis on the costs of absenteeism caused by environmental illness and lost productivity.

Risk Analysis Methods

This section describes the analytical methods that are used to compare and rank different environmental problems within a common framework. Similar, but slightly different, methods are used to analyze human health, ecological, and quality-of-life risks. The criteria used to evaluate information and translate it into a common language for different environmental problems are also similar, with some important differences. And the data sources used for each varies as well. The three different analyses are discussed separately, but the discussion is based on the special aspects of international projects that distinguish them from U.S. studies. Therefore, the following discussion does not substitute for a careful reading of that subject in the relevant section in this document for those who will be conducting the analysis.

Analyzing Risks to Human Health

The human health methodology for comparative risk projects uses the standard risk assessment methods to estimate the magnitude of the health impacts that may occur as a result of exposure to pollutants. Section 2.2 (Assessing Environmental Risks to Human Health) focuses on chemical contamination in industrialized settings. In non-industrialized countries where other environmental health problems are of great concern, other approaches may need to be developed to assess environmental health risks, such as those involving microbial disease and malnutrition.

In general, the methods presented in Section 2.2 are directly applicable to any country. The basic steps of assessing risks to human health are presented below. The first three steps require some adjustments in their application if life styles and environmental problems are markedly different from the domestic context presented in Section 2.2.

Step 1: Hazard Identification

This step involves evaluating available data on the presence of, and hazard posed by, substances likely to cause adverse effects. Typically, in comparative risk projects, the most important and representative "stressor" or stressors for each problem area are selected for analysis.

Step 2: Dose-Response Assessment

This step helps determine the degree of the effect or effects at different doses or levels of exposure to the substance. This relationship between the dose and response is often referred to as the potency or toxicity of the substance. EPA typically makes an important distinction in the "threshold" of different harmful substances. It is assumed that there is *no* threshold or safe level of exposure for carcinogenic substances, while there is assumed to be a level at which exposure to a substance with the potential to cause non-carcinogenic effects is considered to be below threshold or "safe."

These first two steps can be bypassed if incidence data are available. As advocated in Section 2.2, incidence data are preferable because they simplify the process, as long as the causes of disease can be identified with enough certainty. Additionally, they give a more realistic estimate of actual effects than risk estimation. Underreporting, however, is a major concern, especially with non-terminal illnesses.

Step 3: Exposure Assessment

This step in the process traces the most important pathways by which human beings come into contact with or are exposed to a given substance. Having knowledge of the life styles and occupational patterns of people is necessary in order to effectively identify and estimate the magnitude, duration, and frequency of their exposure to harmful substances. Life styles and occupational patterns can be markedly different from country to country. For example, indoor air pollution may require not only a knowledge of the types of fuels used in the home, but also of cooking and heating practices, building materials and structures, and ventilation techniques. Where possible, the exposures of different socioeconomic groups should be taken into account.

The values used for dose-response and exposure parameters should be carefully considered in each instance, since assumptions made for application to U.S. populations may not be appropriate for other countries. Cultural and physiological differences should be considered in determining consumption and exposure patterns. For example, in the United States, the average adult consumes approximately two liters of water per day and weighs 70 kilograms; it would not be appropriate to apply these values to other countries without justification. In some places, people may use bottled water for drinking purposes. Genetic differences have also been known to alter dose-response relationships. Such differences, in general, are minor compared to the magnitude and type of exposure. Therefore, it is recommended that efforts be centered on identifying the magnitude and type of exposure more than possible genetic dose-response differences.

In the Bangkok study, microbiological diseases were a major human health threat. Therefore, they were analyzed as a separate problem (see Exhibit 4.1.4). In analyzing data on the incidence of such disease, analysts may also encounter several problems that were of concern in the Bangkok study. One problem is that many of these diseases are not treated and are not reported. As a result, analysts may need to indicate to decision makers that their risk estimates (based on incidence data) probably represent underestimates of the actual magnitude of the risk, although there is no way for them to know how much they are underestimating the actual risks. Other adjustments may be necessary if microbial diseases cannot be attributed solely to environmental causes. For example, poor personal hygiene and food preparation or inadequate medical care may be of equal or greater importance than environmental factors. Thus, in comparing the health risks from different environmental problems, not all the estimated cases of microbial disease should be attributed to environmental causes.

Exhibit 4.1.4:
Microbial Diseases Addressed in Bangkok Study

Key microbiological diseases that are environmentally related (partial list):	Acute diarrhea Dysentery Enteric fever (typhoid, paratyphoid) Encephalitis Tetanus Acute poliomyelitis Typhus and other rickettsioses
These diseases are responsible for:	6% of deaths in Bangkok 850,000-1,700,000 estimated cases/year
Primary routes of transmission:	Human fecal to oral Vectors (mosquitos, rats, flies)
Environmental factors in disease transmission:	Lack of water Lack of sewage conveyance Contaminated water Lack of sewage treatment Uncollected solid waste Flooding
Non-environmental factors in disease transmission:	Poor personal hygiene Inadequate health care and education Lack of toilets Overcrowding and poor housing Poor nutrition and food preparation

Source: U.S. Agency of International Development. Office of Housing and Urban Programs. *Ranking of Environmental Risks in Bangkok, Thailand.* December 1990.

Step 4: Risk Characterization

The final step of the health risk assessment process is risk characterization, which combines the information obtained from the hazard identification, dose-response, and exposure assessments to allow decision makers to evaluate and compare the relative risks posed by various environmental problems. Risk characterization synthesizes information on the severity, reversibility, individual or population exposures, equity, and uncertainty of adverse health effects estimates by using the same criteria to evaluate all problem areas. By bringing this information to bear on the decision-making process, risk characterization forms an essential link between risk assessment and risk management, providing a framework to compare and rank different problem areas in a consistent and credible way. Once the problems are ranked, then decisions can be made about what to do about them in the next phase of a comparative risk project: risk management.

Analyzing Ecological Risks

The ecological component of the comparative risk process systematically applies ecological risk assessment principles to assess, evaluate, and rank the ecological risks associated with different environmental problems. Ecological risk analysis evaluates the likelihood of adverse ecological effects occurring as a result of exposure by ecological receptors (e.g., a group of white-tailed deer, or a community of interacting animal and plant species) to stressors (e.g., lead, benzene, or road construction), and attempts to characterize the magnitude of these impacts. Section 2.3 (Comparing and Assessing Ecological Risks) provides information on these methods.

The ecological methodology is conceptually similar to the human health methodology, but differs in two distinct ways. First, ecological risk assessment evaluates adverse effects on a myriad of species' interactions and ecological processes, instead of assessing impacts on only a single species (i.e., human beings). Second, ecological risk analyses assess non-chemical or physical impacts, such as rivers that are dammed, wetlands that are drained, forests that are cut, and wildlife habitats that are eliminated. Whereas human health assessments focus on chemical stressors, ecosystems are often adversely affected by chemical *and* physical stressors.

Ecological risk analyses generally consist of four phases, which are described in the following sections.

Phase 1: Problem Formulation

The first phase of a comparative ecological risk assessment involves a systematic planning process to review the list of environmental problem areas, to partition the project area (e.g., a state) into a number of distinct ecological areas, and to select a set of criteria to evaluate ecological risks and rank problem areas. In addition, a preliminary examination of data needs and limitations may be necessary.

Phase 2: Analysis

In the second phase, the goal is to establish a causal link between the problem areas and their ecological effects. Therefore, each problem area is broken down into a set of its most important stressors. The fate and transport of each stressor are then tracked through the environment to determine its ecological effects. This requires knowledge about the toxicity of stressors (for chemical stressors), the exposure or co-occurrence of ecological receptors to stressors, and the response of ecological receptors to stressors.

Where data are lacking or inadequate, professional judgment and consensus building are needed to supplement gaps in data, sources of uncertainty, and a lack of knowledge about complex ecological processes and interactions. For example, non-point source pollution poses risks to many surface-water bodies and coastal areas. One of the major stressors associated with non-point source pollution is the use of nitrogen-based fertilizers in agriculture. The runoff of fertilizers from fields into streams, rivers, and coastal areas is an important exposure pathway. The increases in turbidity and nutrient levels in streams and rivers pose ecological risks to fish habitats and breeding areas, shellfish beds, and to the structure and function of plant communities. Existing data about these ecological effects are gathered and supplemented with judgment and discussion during the analysis phase of a comparative ecological risk assessment.

Phase 3: Risk Characterization

The third phase of a comparative ecological risk assessment involves using the analyses to characterize the risks posed to the environment by different problem areas. Risks are characterized in terms of the evaluative criteria that are developed in the problem formulation phase. Evaluative criteria include such factors as the area, severity, and reversibility of impacts. Values can be assigned to each evaluative criterion using numerical scales or short narrative descriptions. The raw information that provides the basis for assigning values to the various evaluative criteria is often in the form of acres altered or stream miles degraded, changes in plant and animal community structure (i.e., biodiversity), and damages to or declines in the populations of some species. Risk characterization also includes a summary of the assumptions and scientific uncertainties embedded in the analysis, and their anticipated implications.

Phase 4: Comparison and Ranking of Risks

The final phase of a comparative ecological risk assessment involves comparing the ecological risks posed by different problem areas and ranking them. For example, habitat alteration may pose greater ecological risks than solid waste, which might be placed with other problem areas in a lower risk category. This is accomplished by considering the risks to the environment in terms of all the evaluative criteria for each problem area. Thus, the area, severity, and reversibility of impacts as well as the uncertainty of these estimates are considered and compared to other problem areas. Problem areas are then grouped into several categories of risk using a consensus-building process. Professional judgment plays a critical role, but the level of precision required is only as great as that needed to make very rough relative comparisons, rather than absolute estimates, of risk.

Ecological assessment methods are directly applicable worldwide. Data will often be limited to a few ecosystems and must be supplemented with best professional judgment. While the assessment methods used in the United States are transferable, data may not be because species, ecosystems, and classification schemes are likely to be different. Analysts should use local data first, then regional or national data, and finally, data from other countries where conditions are as similar as possible. Alternatively, analysts can establish systems for collecting ecological data, although use of existing data saves considerable time and money. In the absence of complete data sets, ecological analyses can rely on more hypothetical assessments of damages, knowledge of the physical and chemical stressors, and their potential to cause adverse effects using available data.

Analyzing Quality-of-Life Impacts

The quality-of-life analysis is composed of two parts: social impacts and economic damages. These represent impacts to society that are not captured in the human health or ecological analyses of a comparative risk study. Economic damages include the losses resulting from diminished recreational opportunities, a drop in tourism due to environmental degradation or the loss of wildlife, lost productivity and hospitalization costs to people affected by pollution, and damages to crops or forest yields as a result of pollution. Because the monetary values for the parameters were developed to reflect U.S. economic conditions and values, analysts should carefully consider potential differences and reestablish the estimates for parameters based on costs and values specific to the study region.

Social damages can involve an array of concerns, such as negative impacts to people's sense of community, the aesthetic loss of beautiful places, the loss of cultural values due to the disturbance of traditional practices or sacred places, and concern for the well-being of future generations as well as the inequity of impacts on different groups in society. Many social concerns fundamental to the quality of life are difficult to monetize. But this is not to say that they do not exist or are not important. In fact, it is widely recognized that these issues are crucial to a comprehensive study of environmental risks.

Issues surrounding social impacts are so country- and culture-specific that the methods used in the U.S. studies can only serve as a model of American society. Thus, of all the analytical methods used, the social impact analysis will require the most adjustment. Some nations or cultures may wish to derive a whole new methodology. Studies in Africa could use criteria that reflect family and tribal issues. In parts of Central Europe, the environment is in such a poor state that people's concern is to improve the environment so that their children may enjoy it. A study of eastern Africa's Masai might develop criteria that include valuations for cows and eland, two species held in high regard in their culture. In the Hawaii study, cultural criteria included disruption of native Hawaiian life styles, population growth and density, relaxing neighborhoods, access to mountains and the sea, and shared community values and vision (Matsuoka et al. 1992).

While there is no set procedure for conducting a quality-of-life analysis, the following steps provide a framework from which a process can be established and used to measure these types of social and economic impacts. A more full treatment of each step can be found in Section 2.4 of this document.

Step 1: Identify Impacts and Determine the Values of the Community

The values of a community are the basis for an analysis of the impacts of environmental problems on the quality of life. This step is important to assuring that the process has broad support and represents public concerns accurately. Surveys, questionnaires, and public meetings are among the tools sometimes used to help reveal impacts and define community values.

Step 2: Identify and Define Evaluative Criteria

Criteria can be derived from broadly shared public values and applied to each problem area to determine how peoples' lives are adversely affected by environmental degradation. These criteria can include both economic and social impacts, such as economic losses due to lost tourism or recreational use, hospitalization costs and lost productivity, lost peace of mind or sense of community caused by a development project or change in land use, and concerns about the legacy of environmental damages left for future generations.

Step 3: Collect and Analyze Data on Impacts

Once criteria have been selected, the challenge is to find a way to measure the damage from each problem area. Projects may include both quantitative and non-quantitative analysis. The point is to have a well-defined analytic framework and a consistent set of criteria to apply to each problem area. Sources of data can include survey responses, public-opinion polls and census data, anecdotal information, willingness-to-pay studies, direct-cost data, and non-market data.

An assessment of economic impacts should include as comprehensive a picture as possible of the nature and extent of present and anticipated economic impacts caused by environmental degradation. However, models to predict future impacts are often unavailable or are difficult to fit to existing data. Additionally, some aspects of economic impacts assessment (e.g., willingness-to-pay studies) are controversial, especially when results are presented to people who don't have an extensive knowledge of economics. Therefore, deciding which economic impacts to assess and methods to use, and whether to explore future impacts, are among the early decisions that a quality-of-life work group will probably make.

Step 4: Characterize Impacts for All Problem Areas

The data are analyzed quantitatively to provide an estimate of the relative severity of impacts from each problem area and the number of people affected. Wherever possible, non-quantitative information is added to the description of the problem area. Consistent use of criteria and analytic techniques is important to the credibility of the assessment process.

Step 5: Present Findings and Rank Problem Areas for Quality-of-Life Impacts

Quantitative and non-quantitative information is provided for each problem area. It can be presented in charts, matrices, or other devices for purposes of comparing problem areas. The quality-of-life work group, or a policy-level committee advising the work group, uses the information presented to develop a relative ranking of environmental problem areas for quality-of-life issues.

It is important to document the process and methods used in a comparative risk project. This is particularly true for quality-of-life issues, which may require controversial analytic methods or may involve values that are not universally shared. A clear statement of sources, quality, and extent of data; methods used; assumptions made; and degree of uncertainty in results will add to the credibility of assessments. Differing views and core values need to be clarified, respected, and addressed. Where expert opinion is used in the absence of data, it should be clearly stated.

Step 6: Analyze Future Environmental Conditions and Risk Management Considerations

While risk management considerations should be kept separate from risk assessment, it is still important to anticipate and discuss future changes in environmental risk. For the findings of a comparative risk project to remain relevant on a long-term basis, population growth and the values of the community regarding development choices need to be considered. For example, land-development choices to build housing, roads, and factories or to protect natural habitats and tourist attractions, will be affected by demographic trends and will influence the future risks posed by environmental problems. Cleaner industrial processes, substitute chemicals, efficient agricultural processes, and other technological innovations may also affect the future risks associated with problem areas.

Assessing Other Damages

Besides assessing the categories of economic and social effects described in Section 2.4.6, analysts may want to develop simple measures and methods to assess other categories of damages not covered in that section. For example, the economic and social costs of relocating people who migrate from the countryside to the city is a major problem in some countries. In addition to the obvious relocation costs and the burden that urban migration is putting on the infrastructure and social services of many large cities, analysts might develop surveys or other means of determining the perceived loss in the quality of life for those people. To avoid confusion and achieve the best result, the quality-of-life rankings could be presented as two rankings: one covering economic effects and the other, social damages. This is beneficial if an attempt is being made to influence risk management policies or strategies.

Analyzing the exposures of certain socioeconomic groups to contamination can be a good indicator of the level of pollution, and its effects on people. Wherever possible, analyzing highly exposed or highly vulnerable socioeconomic groups separately can be extremely helpful as an early warning of larger problems and in designing risk management strategies to address the greatest risk reduction opportunities. By examining the demographics of the affected populations, managers can determine whether low-income or minority groups may be inequitably subjected to excessive environmental stresses. For example, a native culture that revolves around fishing can be adversely affected economically and medically by damage to a fishery resource because of their reliance on the resource to supplement their diets.

The methods presented in Section 2.4 are designed to estimate the quality-of-life impacts of environmental problems by examining each problem individually. The same approach could be applied to different economic sectors of a country if one goal of a project is to identify the types and amounts of pollution released to the environment by different economic sectors. This approach is discussed in Section 2.1. National income accounts, which are economic bookkeeping systems that track national outputs of goods and services, can provide information at a broader level and may be useful in characterizing the impacts of environmental problems on specific industries. It may be difficult to attribute the impacts of or damages to particular environmental problems, but national accounts can be used as a screening tool to identify the types of effects that warrant more detailed analysis. Some countries are considering including measures of natural resource depletion and other environmental externalities in their national accounting systems (World Bank 1990).

DATA SOURCES AND COLLECTION

Identifying appropriate information sources, collecting data, and putting them in usable form comprise one of the more important tasks of a comparative risk study. Early and effective identification of information and collection of high-quality data will save time and money. In addition to developing the necessary data, data collection and management will benefit environmental managers by highlighting data gaps, identifying future data-collection priorities, and supporting future environmental efforts.

Minimum Data Requirements

Two questions asked in the early stages of the project are: what kind of data does one need, and how much? Some may hesitate to undertake a comparative risk project because they believe that data are not sufficient. Comparative risk uses available data, and, where data are inadequate or unavailable, best professional judgment. The overall objective is to rank the relative risks posed by a comprehensive list of environmental problems, and *relative* risk ranking—not pinpoint accuracy—is all that is required.

Ideally, the data would provide complete and accurate information on the human health, ecological, and quality-of-life impacts of different problem areas. In reality, data are often incomplete, inaccurate or out-of-date, tangential to one's needs, or in a difficult form to use. Thus, the analysis is usually a blend of data and judgment.

Data needs should reflect the project's objectives. For example, a study in a rural area may focus data-collection and analysis efforts on information on agricultural production, pesticide use, natural-resource extraction rates, and rural-living practices. An analysis focused on industrial activity in a metropolitan area may focus on the size, scale, and type of manufacturing, energy use, effluent discharges, local climate conditions, and urban population risks.

Data Sources

Sources of data for any comparative risk analysis are highly dependent on the study area. With the exceptions of toxicity data and possibly data on the release of industrial pollutants, other countries will need to modify U.S. data, if U.S. data are used, as they are site-specific and developed from environmental monitoring for regulatory compliance. Therefore, they reflect conditions for that particular area and are not transferable to other locales.

Relatively basic information can be assembled from a variety of sources to provide sufficient information. Where data are absent or inadequate, then secondary or surrogate data and best professional judgment can be used to fill in the gaps. These indirect sources of data should be evaluated in light of other existing information. For example, risk estimates of the impacts of non-point source pollution on human health can include investigating exposure to pesticides through drinking water and bioaccumulation of pesticides in fish. Data needs and sources for this problem are depicted in Exhibit 4.1.5.

Exhibit 4.1.5:
Potential Data Needs and Sources

Human health concerns associated with non-point source pollution include pesticides in drinking water and residues in fish. A variety of data are needed for risk estimates.

Data Needs	Possible Data Source
Area under cultivation Types of pesticides used Pesticide used per acre	Ministry of Agriculture
Ambient concentration in water # of surface-water supplies # of users	Ministry of Public Works
Fish consumption levels Fish tissue levels	Ministry of Marine and Fisheries
Dose-Response	Integrated Risk Information System

In some cases, alternative data may provide supplemental information that can support the risk analysis. In the Bangkok study, analysts approached members of the municipality with a list of ideal data. Subsequent discussions revealed that such data did not exist, but alternative information describing the outcome or driving force for a given health condition was available. While the new information led to a modification of the analysis, it still provided the best available estimate of risk.

The quality of the data is an important determinant of the quality of the analysis. The more specific the data are to the problem being analyzed, the better the analysis. A hierarchy of data sources should be used to determine the best available information. The most appropriate data will most likely be at the local and regional government levels. Where such specific data are not available, national sources could be used, representing the second tier in the hierarchy. International sources, which often consist of compilations of national data, could be used in the absence of direct local, regional, or national sources.

Local and Regional Sources

Data sources available at the local and regional levels may be the most valuable sources of information, particularly if the study area encompasses only a portion of a country. Local and regional sources might consist of municipal or district government organizations and research institutes, non-government organizations, industries, universities, and hospitals. These sources should have the most reliable data on human health and ecological exposures, natural-resource uses and damages, and disease incidence. In addition, local organizations probably have specific data on pollutant emissions and ambient concentrations for different media (e.g., air, water).

Data come in many forms, including unpublished data files, computer data bases and models, industrial activity reports, university and industry studies, and scientific literature.

The most useful resources for identifying these data will be project participants at the local and regional levels, who should be familiar with the specific data available for problem areas or should be able to identify those who are.

National Sources

Sources of information at the national level can include statistical yearbooks, environmental plans, national publications, economic studies, data bases, computer models, and industrial-activity reports. Such national sources can be particularly useful if the study area involves the whole country, rather than just a portion of it. Federal governments, including environmental and economic ministries, agencies, institutes, and departments, are typical repositories of such sources of information. The United Nations Environment Programme has identified National Focal Points (NFPs), which are national institutions willing and able to provide environmental information upon request; these may be a useful starting point at the national level (UNEP 1993). Non-government organizations may also be useful sources of information with a national focus.

International Sources

Although international agencies and organizations collect data that have a global perspective, this can include data from different countries or for specific ecological regions. Technical staff may have knowledge of applicable international data sources. Coordinators for the NFP's U.N. mission officers and other international representatives will also know what data are available and how to access the data.

In some cases, proxy data will have to be used as a surrogate for data specific to the area. Using proxy environmental data may require revising the estimate on the basis of factors specific to the study area. International data or generic loadings data, such as the World Health Organization's *Management and Control of the Environment*, can fill many data gaps that occur at the local or national level (WHO 1989). However, using proxy data increase uncertainty and the chances for making erroneous assumptions about the area of study.

The U.N. Advisory Committee for the Coordination of Information Systems' *Guide to U.N. Information Sources on the Environment* provides a brief review of the statistical holdings of each U.N. agency and major private organizations (ACCIS 1990). Also of primary importance:

- *U.N. Environment Programme*—UNEP's International Environmental Information System (INFOTERRA) is an international information exchange on all aspects of the environment (UNEP 1992). UNEP also compiles statistical data in its Global Environment Monitoring System (GEMS). This information is published periodically in UNEP's Environmental Data Report (UNEP 1991). Covering a wide range of topics, it has meticulously noted sources, definitions, and data qualifications. All related GEMS information is being entered into the Global Resource Information Database, which compiles georeferenced environmental data for use on Geographic Information Systems. Using both INFOTERRA and GEMS, the respective contact can be identified through the U.N. Development Programme Mission Officer.

- *U.S. Agency of International Development*—U.S. AID is working with most of its bilateral partners in assessing their environmental problems. Environmental assessments and action plans developed as part of these programs can provide useful background information.
- *World Bank*—In addition to a wide range of studies assessing environmental impacts, the Urban Environmental Indicators work of the World Bank has identified a key set of indicators related to impacts, causes, and policy responses.
- *The World Health Organization*—In addition to collecting data and compiling health statistics indicating disease incidence by country, WHO has useful information on food-consumption patterns for different countries.
- *The Food and Agriculture Organization*—In its annual Production Yearbook, FAO compiles statistics for different countries on agricultural, silviculture, and fisheries production and prices; food consumption; and land use (FAO 1992).
- *New on-line computer networks,* such as INTERNET, provide access to data bases, publications, experts, and other environmental data sources.

Data Collection Issues

The availability of data for problem areas is likely to be highly variable. Sometimes, good data may be readily available in a usable form. In other cases, substantial effort will be required to obtain relevant data and to convert it into a usable form. Analysts may encounter obstacles in collecting the data, such as the availability and accessibility of information, the cost of acquiring data, the consistency and accuracy of data, and the time needed to devote to the effort.

U.S. comparative risk analyses are conducted using existing data. In the process, some of the areas identified may warrant additional data collection efforts for future projects. However, if substantial data gaps are identified early that will clearly affect the results of the study dramatically, then collecting new data may be necessary. This section focuses on collecting existing data, as this will be the approach used in most comparative risk studies.

Availability and Accessibility

Because of a lack of reporting requirements in some countries, relevant data are often not collected. Where data are collected, they may be privately held or restricted for use. For example, industrial enterprises in countries with limited environmental regulations may be unwilling to share information on processes and production for fear of pollution control measures being imposed on them or that confidential information will be given to a competitor. A spirit of cooperation should be developed between those individuals and entities with information and knowledge useful to accomplish the project objectives. This will facilitate data collection and analysis, improve the completeness and accuracy of the study, and lay the groundwork for future activities.

Cost of Data Acquisition

In some instances, relevant data may be held by private organizations that require payment for the information. The costs of obtaining data in these situations may make it difficult to obtain it in a timely manner, particularly if resources are a constraining factor. For example, some of the organizations with useful data in Central Europe are being privatized and require payment for information.

Time

Project planners should allocate sufficient time for data collection activities. The amount of time needed depends largely on the size of the study area, the level of the overall effort, and the degree of coordination among organizations managing different types of information. Data collection can be very time-consuming, particularly if multiple organizations have overlapping responsibilities.

Validity and Accuracy

Analysts should be extremely careful in checking the validity and accuracy of the data they use. They should also thoroughly understand the origins of the data to ensure consistency with assumptions used in the analysis. Understanding the source, the collection methods, and the original purpose of the data will help determine whether the information is useful and accurate. The sampling and analytical methods should be examined to determine whether their outputs are reliable and representative, especially if there are various conflicting sources of the same type of information, and to determine the best information source to use.

Often, the hardest task for the technical staff is dealing with limited data or old data. For example, though an area may have good population data, modifications may have to be made to estimate the number of individuals exposed, because the pollution is distributed along natural boundaries, not political. As data are modified or estimates are made, uncertainty increases. It is important that uncertainty from estimates and data be documented. In the absence of data, best professional judgment can be used to arrive at risk estimates.

Risk Management

Risk management is a decision-making process in which the ranking results from the risk assessment process are integrated with economic, technical, social, and political considerations to generate a prioritized set of risk reduction or prevention strategies that will achieve environmental goals. Whereas risk assessment asks how bad the problem is, risk management asks what can and should be done about it. The effectiveness of risk management strategies can be monitored and evaluated in terms of the progress made toward goals. These decisions represent the culmination of the comparative risk process.

Because the objectives of comparative risk studies can be so varied, it is difficult to recommend a single approach to risk management. To ensure success, risk managers must pay careful attention to the risk analysis results and consider other relevant criteria in order to identify the strategic options that will achieve the greatest risk reduction possible with the resources available. The discussion of the risk management phase of a comparative risk project, as presented in Section 3, is applicable to international projects.

Setting Environmental Goals

Environmental goals can serve a number of useful purposes. The process of setting goals can help managers determine which environmental problems are the most serious within the framework of a comprehensive strategy. The process of setting goals also helps identify the types of environmental data needed, thereby focusing data collection and analysis activities. Goals can also provide a context for discussing joint, coordinated actions with other public, non-profit, and private organizations that can help clarify various roles that different parties can play. Finally, goals can also provide important benchmarks against which to measure the costs and benefits of various environmental strategies and efforts. Environmental goals can then be adjusted if the public determines that they are either too low in terms of the level of environmental protection sought or too high in terms of the cost to society. Once the resource demands for all goals are placed within the context of available resources, it may become necessary to decide which goals are most important and which goals may have to be scaled down or implemented over a longer period of time.

The overall objectives of the project will guide the risk management process: which participants are selected, which analytical activities are performed, and which criteria are considered in making risk management decisions. The resulting priorities can be used to allocate environmental resources within a country, restructure environmental regulatory or legal authorities, justify environmental loans from international organizations, and mobilize public and private support for environmental programs. Such ambitious and far-reaching objectives emphasize the importance of having consistent and committed political support for the effort, full participation by all stakeholders and decisions reached by consensus, public involvement and consent, and sufficient resources and time to adequately conduct the process. Participation and cooperation of all major stakeholders is crucial to successful risk management.

Establishing Risk Management Criteria

Once a set of specific, measurable goals has been set, then it is necessary to establish risk reduction or prevention strategies to achieve these goals. In selecting risk management strategies, it is necessary to first decide what criteria will be used to evaluate possible risk management strategies. The criteria used to evaluate potential risk management strategies, their relative importance, and the analytical tools used to incorporate them in the process will vary, depending on the objectives of the process. Each proposed strategy can then be evaluated against a common set of criteria to determine its feasibility and relative advantage compared to other strategies that might be implemented.

There is no "correct" set of risk management criteria. Participants can consider criteria that have been used in previous projects, add or substitute other criteria, and find a set of evaluative criteria that work best for their project. For example, if one of the objectives of a project is to build environmental institutions by developing and/or restructuring environmental research, environmental education, monitoring, and regulatory authorities, then existing statutory and regulatory authorities, institutional capabilities, the amount of risk reduction, cost, and ease and speed of implementation would be the most important and pertinent criteria to consider in this case. Some criteria that have been used in a number of comparative risk projects include cost and cost-effectiveness, technical feasibility, statutory authority, public support, equity considerations, the ease and speed of implementation, and the likelihood of the strategy being successful. These criteria are discussed more fully in Section 3.1.

Selecting Strategies to Achieve Environmental Goals

The purpose of this step is to select risk management strategies through an iterative process that gradually focuses on the most effective means of achieving environmental goals. Risk management decisions in international studies may have broader economic and social implications than those in past U.S. studies. These implications may require analysis of the effects of risk management strategies on the economy and in the broader social context. Frequently, countries link their environmental action plans to national priorities and economic policies. Within this large context, the risk management approach becomes far more important and influential.

Opportunities and constraints are different and should be maximized to their fullest potential. In many countries, risk management strategies that impose costs on developing or struggling industries can be perceived as impeding economic growth. In such situations, an analysis of how economic development and environmental protection can be maximized is advisable; however, the analysis should consider the full costs of economic development, including negative externalities associated with industrial development. The analysis may also include an estimate of the social costs and benefits to determine the net social-welfare impacts. Risk management strategies may also incorporate an analysis of projected land use, population, and economic trends. The developed strategy should be compared to existing environmental strategies to determine if they are better approaches to addressing the problem.

To start the process, work group members may propose risk reduction or prevention strategies from a "tool box" of risk management approaches. It may be very helpful to introduce work group members to a round-table discussion of various risk management approaches and how they work. Different risk management approaches are depicted below, and a more full discussion of them can be found in Section 3. Proposed strategies can then be analyzed in terms of the criteria that have been selected by the work group to evaluate the merits of various strategies. The more promising strategies can then be subjected to more rigorous analysis until consensus is reached on which ones to select for implementation. By focusing the analysis of strategies on environmental goals, it may be more likely that common links between different problems will be identified and simultaneously addressed.

Different risk management approaches include:

- Scientific and technological measures
- Provision of information to the public
- Market incentives and disincentives
- Conventional regulations
- Effective and innovative enforcement
- Interagency and international cooperation

Different strategies and approaches exist within risk management options. Pollution-prevention strategies are generally designed following the pollution-prevention hierarchy. At the top of the hierarchy, the most preferential option is source reduction and substitution. The hierarchy then proceeds to the option of second choice, which is recycling, and on to treatment and control, disposal, mitigation, and finally remediation as the option of last choice.

Apart from the proposed risk management strategies, participants in this process may wish to consider broader institutional/political issues, such as:

- Resources required
- Relationships with key stakeholders
- Key organizational policies
- Flexibility or adaptability of strategy
- Effects on other organizations
- Rule, policy, and statutory changes required

Implementing Strategies and Monitoring the Results

The purpose of this final step in the risk management process is to implement the risk management strategies that are selected by the work group, and to monitor the results to ascertain that progress is being made toward the environmental goals. While there are some ideas or "lessons learned" from past projects that can be described, it would be unrealistic to assume that there are simple rules or advice that can be offered about how to select the best strategies. What seems most important is to acknowledge the complexity of the task.

The process of selecting the most promising risk management strategies is a difficult process. Because so many criteria are involved and goals can range from reducing health risks to increasing environmental equity to spreading agency resources across an increasing number of environmental challenges, no single set of comparisons is possible. No scientific rule will tell work group members the relative importance of human health risks v. ecological risks. No weighting formula is likely to satisfy every member's sense of the relative importance of the different criteria. In fact, the relative importance of each criterion is probably not something that remains constant across all environmental problems, and is likely to change depending on the problem under discussion.

Structuring the decision-making process in a way that maximizes its integrity and relevance is crucial to the likelihood that the work group's decisions will actually be carried out. A vigorous and open discussion of the relative advantages and disadvantages of strategies among a diverse and knowledgeable work group will lend integrity to the process. The process will more likely be relevant and credible to those who have the ultimate authority to implement the strategies if it has included the right people, used appropriate criteria, and been reported clearly and persuasively.

Once risk management strategies are selected, then they must be implemented and monitored over time to ensure that environmental conditions are changing in the direction of the environmental goals that have been established. The risk management work group should be prepared to present well-defined and credible strategies that will achieve broadly supported goals in a way that meets the public's interests and needs. Implementation is more likely to succeed if the strategies are part of an overall strategic plan that firmly ties environmental policies to budgets and meaningful, measurable results. Monitoring the actual results of the strategies will help environmental managers and the public know if their efforts are working or if they need to be adjusted and revised.

Alternative Views of Strategy Development

Risk management options need not always be developed within the sectoral, organizational, or media categories used during the technical analysis. At times, such categorization can channel solutions along technical lines that ignore critical social, economic, and institutional factors. An alternative approach is to classify problems along a spatial scale where appropriate economies of scale, governmental levels, and social norms can be maximized to their fullest extent (see Tables 4.1.2 and 4.1.3). This approach benefits lesser-developed and newly industrialized nations that need to consider how to focus risk management strategies activities at the appropriate level.

This example, modified from the work of the UNDP/World Bank/UNCHS (Habitat) Urban Management Program (forthcoming) presents characteristic problems of the urban environment in lesser-developed nations. In Table 4.1.1 problem areas are spatially distinguished, as are key infrastructure and services.

In Table 4.1.2, selected problems for a given spatial level are presented, along with possible solutions. The options presented descend in order of preferred risk management options, following the EPA's Pollution Prevention Hierarchy. In general, the most cost-effective solutions are those at the top of the hierarchy. Administration and implementation for each activity best correspond to the associated government level. For example, in the case of toxic dumps, municipalities are best equipped to zone facilities in a common area, license facilities, and monitor their compliance. Communities would find it difficult to achieve this goal, given their more narrow focus and limited resources.

In some cases, cross-spatial relationships can be identified, and joint activities can be developed. Municipal waste collection is an example of this. Community governments must oversee refuse collection, but municipalities are responsible for landfill management. Transboundary issues (i.e., the import and export of pollution) must also be analyzed. For example, the source of water pollution can occur at almost any level and can have a broad range of impacts.

Table 4.1.2:
Spatial Scale of Urban Environmental Problems

Spatial Scale of Impact Increasing →

	Home	Community	Metropolitan Area	Region	Continent/Planet
Key Infrastructure & Services	Shelter Water storage On-site sanitation Garbage storage Stove ventilation	Piped water Sewerage Garbage coll. Drainage Streets/lanes	Industrial parks Interceptors Treatment plants Outfalls Landfills	Highways Water sources Power plants	
Characteristic Problems	Substandard housing Lack of water No sanitation Disease vectors Indoor air poll.	Excreta-laden water/soils Trash dumping Flooding Noise/stress Natural disasters	Traffic congestion Accidents Ambient air pollution Toxic wastes	Water pollution Loss of wetlands, and aquatic and terrestrial habitats	Acid rain Global warming Stratospheric ozone depletion

Table 4.1.3:
Examples of Problems and Appropriate Types of Solutions

	Home	Community	Metropolitan Area	Region	Continent/ Planet
Appropriate Level of Action →	Head of Household	Community Council	Municipality	Regional/Provincial Government	National or Transboundary
Environmental Problem Area →	**Indoor Air**	**Excreta-laden Water/Soil**	**Toxic Wastes**	**Loss of Wetlands**	**Acid Rain**
Solutions following Pollution Prevention Hierarchy (Increasing Costs ↓)					
Source Reduction/ Substitution	Alternative fuels Fuel-efficient stoves		Waste minimization Efficient fuels	Greenways Watershed protection areas	Alternative fuels Low-sulfur coal
Recycling		Methane gas converters Compost	Industrial recycling Use of grey water		
Treatment and Control		Septic tanks	Industrial waste-water facilities	Water treatment facilities	
Mitigation			Licensed hazardous waste facilities		
Remediation	Ventilation	Night soil collection Sewage lines	Zoning		
Disposal			Hazardous waste cleanup	Wetland restoration	

REFERENCES

Advisory Committee for the Coordination of Information Systems (ACCIS). *ACCIS Guide to United Nations Information Sources on the Environment,* no.2. Geneva, Switzerland. 1990.

Food and Agriculture Organization. *Production Yearbook.* Rome, Italy. 1992.

Matsuoka, Jon, Davianna McGregor, and Luciano Minerbi. Native Hawaiian and Cultural Assessment. *Phase 1: Problems/Assets Identification.* Honolulu: University of Hawaii at Manoa. December 1992.

United Nations Development Programme (UNDP)/United Nations Center for Human Settlements (UNCHS)/International Bank for Reconstruction and Development (IBRD). Urban Management Program. "Environmental Profile of Katowice; Poland." Draft. 1991.

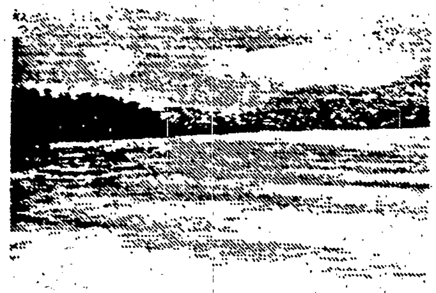
UNDP/World Bank/UNCHS. Urban Management Program. "Environment Strategies for Cities: A Framework for Urban Environmental Planning and Management in Developing Countries." Discussion Paper Series (forthcoming).

United Nations Environment Programme (UNEP). International Environmental Information System (INFOTERRA). *National Focal Points: Address Directory.* Nairobi, Kenya. 1993.

UNEP. INFOTERRA. *International Directory of Sources,* 7th ed. Vols. A-C. Nairobi, Kenya. 1992.

UNEP. *Environmental Data Report,* 3d ed. Prepared by Basil Blackwell. Oxford, England. 1991.

U.S. Agency for International Development (AID). Office of Housing and Urban Programs. *Ranking Environmental Risks in Bangkok, Thailand.* Washington, D.C. 1990.



Appendix 1
Revised Core List of Environmental Problem Areas for Regional Comparative Risk Projects

Environmental Problem Areas

Industrial Waste-Water Discharges to Oceans, Lakes, and Rivers

These are sources of pollution that discharge effluents into surface waters through discrete conveyances such as pipes or outfalls. This problem area does not include publicly and privately owned municipal waste-water discharges. Pollutants of concern include total suspended solids; BOD; toxic organics, including pthalates and phenols; toxic inorganics such as heavy metals; and thermal pollution. Typical sources of discharge include metal finishing, pulp and paper processing, and iron and steel production. Facilities requiring permits under the National Pollution Discharges Elimination System (NPDES) fall under this problem area.

Municipal Waste-Water Discharges to Oceans, Lakes, and Rivers

This problem area includes all constituents of the outfalls of publicly and privately owned treatment facilities. Both municipal sewage treatment outfalls and industrial discharges that flow through publicly operated treatment works are included in this problem area. Major contaminants include all those found under Industrial Wastewater Discharges to Oceans, Lakes, and Rivers, plus ammonia, chlorination products, and nutrients. Combined Sewer Overflows (CSO's) are included in this problem area.

Aggregated Public and Private Drinking-Water Supplies

As drinking water arrives at the tap, it may contain a wide variety of contaminants from both natural and man-made sources, and point and non-point sources. Since many of the contaminants can be traced to other problem areas, Drinking Water risk evaluation will involve much double-counting with those other problem areas (Industrial Waste-Water Discharges, POTW Discharges, Non-point Source Discharges, Storage Tanks, hazardous and non-hazardous waste problem areas, etc.). Drinking Water is included as a problem area because remediation/treatment options can occur either at the *source* of contamination (the other problem areas) or at the *delivery system* of the drinking water (treatment or switch to alternative supplies). Drinking Water includes both delivery systems that serve 25 or more people and are therefore covered by the Safe Drinking Water Act, and those which serve fewer than 25 people and are not so covered. Pollutants of concern include disinfection byproducts, pesticides, inorganics (such as heavy metals), radionuclides, toxic organics, fluoride from natural sources, and microbiological contaminants.

Non-point Source Discharges to Oceans, Lakes, and Rivers

This category includes pollutants that reach surface waters through sources other than discrete conveyances for effluents. This includes runoff from agricultural, urban, industrial, silvicultural, or undisturbed land. Possible pollutants are quite varied, although they include most of the constituents of the point source discharges to surface waters. Storm water carries a large amount of solids, nutrients, and toxics. Other sources included in this problem area are: surface discharge of septic tanks, contaminated in-place sediments, air deposition of pollutants (except for acids), and mine drainage. Pollutants *not* included in this problem area are acid deposition, solid waste disposal, hazardous waste sites (RCRA & CERCLA), pesticide runoff, and physical impacts from discharges of dredge and fill material.

Physical Degradation of Water and Wetland Habitats

Damages arising from alterations in the quantity and flow patterns of ground water and surface water are included in this problem area. Such disturbances include channelization, dam construction and operation, surface and ground-water withdrawals, construction and flood control, irrigation distribution works, urban development, and the disposal and runoff of dredge and fill materials. Physical changes to water flow and aquatic habitats are included in this problem area, as is chemical contamination resulting from physical changes (e.g. dredging of contaminated sediments).

Aggregated Ground-Water Contamination

All forms of ground-water pollution, including sources not counted in other problem areas, compose this problem area. These include fertilizer leaching, septic systems, road salt, all injection wells, non-waste material stockpiles, pipelines, and irrigation practices. The list of possible contaminants is extensive and includes nutrients, toxic inorganics and organics, oil and petroleum products, and microbes. As with drinking water, there is much double-counting in this problem area. It is included as a separate "special" problem area like drinking water because a true understanding of the overall risks to this resource is particularly important, and because such an understanding is difficult if the risks are split between many different problem areas.

Storage Tanks

Storage Tanks includes routine or chronic releases of petroleum products or other chemicals from tanks that are above, on, or underground; tanks owned by farmers; fuel oil tanks of homeowners; or other storage units (such as barrels). Stored products include motor fuels, heating oils, solvents, and lubricants that have air emissions or can contaminate soil and ground water with such toxics as benzene, toluene, and xylene. This category excludes hazardous waste tanks. Acute releases (explosions, tank collapse) are examined under Accidental releases.

RCRA Hazardous Waste

This category generally includes the risks posed by active and inactive hazardous waste sites regulated under the Resource Conservation and Recovery Act (RCRA). These sites include RCRA open and closed landfills and surface impoundments, hazardous waste storage tanks, hazardous waste burned in boilers and furnaces, hazardous waste incinerators, and associated solid waste management units. Seepage and routine releases from these sources contaminate soil, surface water, ground water, and pollute the air. Contamination resulting from waste transportation and current illegal disposal are also included. Radiation from hazardous "mixed waste" from RCRA facilities is included in this problem area.

Hazardous Waste Sites — Abandoned/Superfund Sites

This category includes hazardous waste sites not covered by RCRA, but by Superfund. Most are inactive and abandoned. Sites can be on the National Priority List (NPL), deleted from the NPL, candidates for the NPL, or simply be noted by the Federal Government or states as unmanaged locations containing hazardous waste. Sites may contaminate ground or surface water, pollute the air, or directly expose humans and wildlife. There are many pollutants and mixtures of pollutants, including TCE, toluene, heavy metals, and PCB's. Radiation from hazardous "mixed waste" in abandoned/Superfund sites is included in this problem area.

Municipal Solid Waste Sites

Municipal Solid Waste Sites includes open and closed municipal landfills, municipal sludge and refuse incinerators, and municipal surface impoundments. These sources can contaminate ground and surface water and pollute the air with particulates, toxics, BOD, microbes, PCDF's, PBB's, and nutrients. Contamination may occur through routine releases, soil migration, or runoff. Most sites are regulated under Subtitle D. This category excludes active and inactive hazardous waste sites.

Industrial Solid Waste Sites

Industrial Solid Waste Sites includes open and closed industrial landfills, industrial sludge and refuse incinerators, and industrial surface impoundments. These sources can contaminate ground and surface water and pollute the air with particulates, toxics, BOD, microbes, PCDF's, PBB's, and nutrients. Contamination may occur through routine releases, soil migration, or runoff. Most sites are regulated under Subtitle D. This category excludes active and inactive hazardous waste sites. Although the list of potential contaminants is similar to municipal solid waste sites, the concentrations, volumes, and mixes of pollutants found on typcial sites are frequently very different.

Accidental Chemical Releases to the Environment

Contaminants are accidentally released into the environment in a variety of ways during transport or production. An industrial unit may explode and emit toxics into the air, a railroad tank car may turn over and spill toxics into surface water or roads, or a ship may run aground and spill oil or other cargo into the environment. Damages to property, personnel, and wildlife may occur from intense, short term releases of toxic or flammable chemicals. Acids, PCB's, ammonia, pesticides, sodium hydroxide, and various petroleum products have been accidentally released.

Pesticides

This problem area addresses risks arising from the application, runoff, and residues of pesticides to humans and the environment. It includes risks to people applying agricultural pesticides, including farm workers who mix, load, and apply them. Also included are risks to the public and non-target plants and wildlife as a result of short range drift, overspray, and misuse. Some of the more dangerous substances include ethyl parathion, paraquat, dinoseb, EPN, aldicarb, and diazinon. Disposal of mixed pesticide wastes has resulted in the generation of highly toxic, largely unknown byproducts that have entered the air and caused serious health problems. Suburban spraying of property, often done with high pressure systems, can result in contamination of neighboring property, residents, pets, and livestock. Aside from direct exposure, additional pesticide risks stem from exposure through ingestion of residues on foods eaten by humans and wildlife. Bioaccumulation and food chain effects are also included in this category. Note that accidental releases, ground-water contamination, and indoor air pollution from pesticides are respectively included in the Accidental Releases, Aggregated Ground Water, and Indoor Air problem areas.

Sulfur Oxides and Nitrogen Oxides (Including Acid Deposition)

Sulfur Oxides and Nitrogen oxides cause a wide variety of primary and secondary effects. Primary effects include health, visibility, and welfare impacts. A major secondary effect is acid deposition, which results from chemical transformation of oxides of sulfur and nitrogen, producing acid rain, snow, and fog, as well as dry deposition. Acid deposition alters the chemistry of affected aquatic and terrestrial ecosystems, damaging plant and animal life. Sources are a wide variety of industrial, commercial, and residential fuel and related combustion sources. This problem also includes visibility effects resulting from the long range transport of sulfates.

Ozone and Carbon Monoxide

Ozone and Carbon Monoxide are major air pollutants in many areas, arising from both mobile and stationary sources. Damage to forests, crops, and human health can be severe. Note that volatile organic compounds (VOC's) are critical precursors to ozone formation, but the direct effects of VOC's are included in the Air Toxics problem area. To the extent that VOC's result in ozone, those ozone effects are captured by this problem area.

Airborne Lead

Air emissions of lead result from many industrial and commercial processes. This problem area includes both direct exposure to airborne lead and exposure to deposited lead from airborne sources. It does not include exposure to lead from drinking-water delivery systems, or lead found in homes and buildings from leaded paint.

Particulate Matter

Both total suspended particulates and fine particulates/PM 10 are included in this problem area. Major sources include motor vehicles, residential fuel burning, industrial and commercial processes, and in some cases strip or open pit mining.

Hazardous/Toxic Air Pollutants

This problem area covers outdoor exposure to airborne hazardous air pollutants from routine or continuous emissions from point and non-point sources. Pollutants include asbestos, various toxic metals (e.g., chromium, beryllium), organic gases (benzene, chlorinated solvents), polycyclic aromatic hydrocarbons (PAHs, such as benzo(a)pyrene, primarily in particulate form), gasoline vapors, incomplete combustion products, airborne pathogens, cooling towers, and a variety of other volatile organic chemicals and toxics. The problem area covers exposure through both inhalation and air deposition of these pollutants to land areas. Runoff of deposited pollutants to surface waters is addressed in Non-point Sources. Major sources include large industrial facilities, motor vehicles, chemical plants, commercial solvent users, and combustion sources. This category excludes, to the extent possible, risks from pesticides, airborne lead, radioactive substances, chloroflourocarbons, emissions from waste treatment, storage and disposal facilities, storage tanks, and indoor air toxicants.

Indoor Air Pollutants Other Than Radon

This category applies to exposure to accumulated indoor air pollutants, except radon, primarily from sources inside buildings and homes. These sources include unvented space heaters and gas ranges, foam insulation, pesticides, tobacco smoke, wood preservatives, fireplaces, cleaning solvents, and paints. The pollutants include tobacco smoke, asbestos, carbon dioxide, carbon monoxide, nitrogen oxides, lead, pesticides, and numerous volatile organic chemicals such as benzene and formaldehyde. Occupational exposures are included, as is inhalation of contaminants volatilized from drinking water.

Indoor Radon

Radon is a radioactive gas produced by the decay of radium, which occurs naturally in almost all soil and rock. Risks occur when radon migrates into buildings through cracks or other openings in the foundation, water, or fuel pipes. The gas is trapped by dense building materials and can accumulate to very high levels. When inhaled, radon decay products can cause lung cancer. This category includes radon volatilized from domestic water use, and also includes occupational exposures. The problem area does not include outdoor radon.

Radiation Other Than Radon

Exposure to ionizing and non-ionizing radiation (beyond natural background) is included here. Sources of radiation included in this category are: radio frequencies (also T.V. transmitters, power lines, radar, microwave transmissions, and radiation from home appliances and wiring); radiation from nuclear power operations; high-level radioactive waste (including spent reactor fuel) and low-level waste (including radiopharmaceuticals and laboratory clothing from hospitals involved in nuclear medicine, and tools used in cleaning up contaminated areas, etc.); and residual radioactivity (including the decommissioning of facilities, such as laboratories and power plants that use radioactive materials). Also included in this category are industrial processes, such as uranium mining and milling, and the mining of phosphate. Radiation resulting from nuclear accidents where radioactivity is released is included under Accidental Releases. Medical exposures (X-rays, radiation therapy) and exposure from ozone depletion are not included.

Physical Degradation of Terrestrial Ecosystems/Habitats

Sources affecting terrestrial ecosystems/habitats include both chemical and non-chemical stress agents. Because chemical sources of degradation are addressed in other categories, this category includes physical modifications (such as mining and highway construction) and other sources of degradation (such as dumping of plastics and other litter) that affect terrestrial ecosystems/habitats. Effects on undisturbed lands/habitats that result from nearby degradation (habitat fragmentation, migration path blockage) are also included in this problem area. EPA often has no regulatory authority over sources of physical degradation, while in other cases it may be able to influence them through the NEPA/EIS process.

Optional Problem Areas

Odor and Noise Pollution

Although this problem area was not considered by the three previous regional projects, it was examined in Unfinished Business and covers a legitimate set of environmental concerns. If examined, regions should exclude all effects associated with the sources of the odors and noise, other than the odors and noise themselves. Noise from a construction site, for example would fall under this problem area, while habitat destruction would be captured by Non-chemical Degradation of Terrestrial Ecosystems/Habitats, and chemical runoff would fall under Non-point Sources.

Stratospheric Ozone Depletion

The stratospheric ozone layer shields the earth's surface from harmful ultraviolet (UV-B) radiation. Releases of chloroflourocarbons (CFC's) and nitrogen dioxide from industrial processes and solid waste sites could significantly reduce the ozone layer. Although this is clearly a national and international problem, regional projects may wish to estimate their region's contribution to the problem, and analyze the effects of ozone depletion on their region.

Appendix 2
Comparative Risk Contacts and Resources

CO_2 AND GLOBAL WARMING

Atmospheric concentrations of carbon dioxide (CO_2) are projected to increase over the next century due to an increase in fossil fuel combustion and a decrease in tropical rain forests and other CO_2 sinks. Higher levels of CO_2 may raise climatic temperatures globally, raising the sea level and disrupting weather patterns. As with Stratospheric Ozone Depletion, this is clearly a national and international problem, but regional projects may wish to estimate their region's contribution to the problem and the likely effects of the problem on their regions.

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RESOURCES

Leap to 2000: Louisiana's Environmental Action Plan. Project Report : The Negotiated Single Text of the Public Advisory and Steering Committees. Louisiana Department of Environmental Quality. Baton Rouge, LA. November 30, 1991.

Environment 1991: Risks to Vermont and Vermonters. A report by the Public Advisory Committee, The Strategy for Vermont's Third Century. Vermont Agency of Natural Resources. Waterbury, VT. July 1991.

Reducing Risk: Setting Priorities and Strategies for Environmental Protection (SAB-EC-90-021). U.S. Environmental Protection Agency. Science Advisory Board. Washington, D.C. September 1990.

Toward 2010: An Environmental Action Agenda. Environment 2010: A joint project of the State of Washington and the U.S. EPA. Washington Department of Ecology. Olympia, WA. July 1990.

Final Report: Colorado Environment 2000. Governor's Citizen Advisory Committee. Colorado Environment 2000. Denver, CO. June 1990.

Unfinished Business: A Comparative Assessment of Environmental Problems. U.S. Environmental Protection Agency. Washington, D.C. February 1987.

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