COMPARATIVE RISK PROJECTS AND THEIR EFFECTS ON DECISION MAKING

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I. INTRODUCTION

Throughout the past few decades, both environmentalists and critics have been concerned that our nation's efforts to reduce environmental risk have been inconsistent, uncoordinated, and therefore less effective because of the fragmented nature of environmental policy, laws, and institutions.[1] Separate laws have been enacted in response to high-profile episodes of environmental concern, and this has resulted in the U.S. Environmental Protection Agency, as well as other agencies and departments, being structured into splintered offices that are relatively independent and uncoordinated. This fragmentation inhibits priority-setting. Nevertheless, government must assess the range of environmental problems of concern and target protective efforts to address the problems that seem to be the most serious.[2] According to the Carnegie Commission, "agencies should experiment with methods to integrate societal values into relative risk analyses where statutes do not supply all the value judgments necessary to rank risks."[3]

Comparative risk projects are one such method that would greatly aid in reducing both risks and costs by developing quantitative measures to compare different risks to human health, ecological health, and social welfare, and to help society choose more wisely among available policy options.[4] Such projects have been performed by federal agencies and departments as well as by states since the late 1980s. The quantitative measures developed allow us

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1. *See* SCIENCE ADVISORY BD., U.S. EPA, REDUCING RISK: SETTING PRIORITIES AND STRATEGIES FOR ENVIRONMENTAL PROTECTION 1 (1990).

2. *See id.*

3. *How Safe is Safe Enough? Risk Assessment and the Regulatory Process: Hearing Before the Subcommittee on Investigations and Oversight of the Committee on Science, Space, and Technology, 103rd Congress First Session* 202 (1994) [hereinafter *How Safe is Safe Enough?*] (statement of Alvin L. Alm, Dir. and Sector V.P., Science Applications Int'l Corp.).

4. *See* SCIENCE ADVISORY BD., *supra* note 1, at 2.

to respond more effectively to current problems and to predict future problems.[5] According to former EPA Director William Reilly, comparative risk analysis allows governments to allocate resources so as to realize the greatest benefits for human health, and thus maintain the integrity of natural ecosystems by focusing on the most significant and troublesome risks first.[6]

Despite the variety of potential benefits from these projects, very little work has been done to critique, compare, and contrast the content of the various completed comparative risk projects (not including budget analysis) in publication. Therefore, this paper will seek to analyze the following three comparative risk projects: the 1987 U.S. Environmental Protection Agency Unfinished Business project[7] done by Agency staff, the 1990 U.S. Environmental Protection Agency Reducing Risk project done by the Science Advisory Board (SAB)[8] (performed in order to validate or invalidate the 1987 project), and the 1994 California Comparative Risk Project[9]. They will be assessed according to project objectives, methodologies, ranking criteria, and final ranked lists.

II. OBJECTIVES OF THE COMPARATIVE RISK PROJECTS

The EPA's driving force for its 1987 project methodology was to find ways of applying its finite resources to yield the greatest effect in minimizing risk. The EPA's concern was the high cost of minimizing less-severe risks. The marginal cost continues to increase as zero risk

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5. *See How Safe is Safe Enough?, supra* note 3, at 202-03.

6. William Reilly, *Taking Aim Toward 2000: Rethinking the Nation's Environmental Agenda*, 21 ENVTL. L. 1359, 1363-64 (1991).

7. 1 U.S. EPA, UNFINISHED BUSINESS: A COMPARATIVE ASSESSMENT OF ENVIRONMENTAL PROBLEMS (1987) ("overview" report).

8. SCIENCE ADVISORY BD., *supra* note 1.

9. CALIFORNIA COMPARATIVE RISK PROJECT, TOWARD THE 21ST CENTURY: PLANNING FOR THE PROTECTION OF CALIFORNIA'S ENVIRONMENT (1994). A fourth project, the 1991 Department of Energy (DOE) Priority System for Environmental Restoration was also analyzed but will not be addressed in this paper since it placed the strongest emphasis on the use of the comparative risk tool simply as a means of budget allocation. The DOE risk ranking included such national objectives as reducing risks to human health and the environment, avoiding adverse socioeconomic impacts, responding to regulatory requirements and reducing uncertainty. *See* Survey and Evaluation of Environmental Decision Support Tools, Report Prepared by ICF Kaiser Incorporated for the U.S. Department of Energy (1993) (on file with author) [hereinafter ICF Kaiser Inc.]. However, this risk ranking was applied to the budget request that DOE sent to the Office of Management and Budget. This request was subsequently placed in the President's budget submitted to Congress. The ranking is used to determine fund allocations if Congress' final appropriation is not sufficient for the Department to successfully implement all programs. *See id.*

is approached. Therefore, in order to maximize the cost-effectiveness of risk reduction, the EPA concluded that priority must be given to those environmental problems that pose the greatest risk to society.[10]

The objectives of the 1990 risk ranking project included (1) comparing the SAB scientists' ratings to those of the EPA managers by critically reviewing the previous EPA project, (2) combining the evaluations of cancer and noncancer with ecological and welfare rankings, which were left as separate lists in 1987, (3) providing policy options for reducing major environmental risks, and (4) developing long-term assessment and ranking methodologies that could serve as a foundation for future projects.[11] Ultimately, the results of this project were to be used in setting regulatory and budget priorities.

The California project's driving force was one of minimizing risk as opposed to making budget decisions. It had four key objectives: (1) to assess and rank environmental threats to human health, ecological health, and social welfare, (2) critique the risk ranking model used by California and analyze alternative models for environmental protection and priority-setting (which is similar to the 1990 SAB project), (3) incorporate public input into the discussion of environmental priority-setting, and (4) attain a consensus among the many perspectives. The goal was to rank selected environmental problems according to their relative severity.[12]

III. RANKING PROCEDURE

Conventional risk-ranking models, such as that used in the 1987 U.S. EPA project, have only a two-stage process: (1) development of a list of environmental problems to analyze; and (2) analysis by project participants (usually not the public) of the associated risks and ranking them by the severity of the problem.[13] The 1990 SAB project did not directly discuss a particular risk ranking procedure, but based on its objectives, it appears to have followed the same two-step process used in its predecessor, plus an additional step involving the critique of the 1987 procedure.[14]

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10. *See* U.S. EPA, *supra* note 7, at ii.

11. *See* SCIENCE ADVISORY BD., *supra* note 1, at 5.

12. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 67-69.

13. *See* SCIENCE ADVISORY BD., *supra* note 1.

14. *See id.* Interestingly, in its project the DOE used a four-step process involving two distinct rankings; one of environmental hazards and the other of budget scenarios, the latter of which relies on input from the first ranking. *See* ICF Kaiser Inc., *supra* note 9. The first step utilized the hazard ranking in which environmental assessment and restoration activities proposed for the year of concern were categorized into temporal categories based on urgency.

California altered the two-step process of the 1987 EPA project to include three components. "Risk Ranking" involved quantifying risks, issues, and judgments associated with environmental problems. "Critiquing the Risk-Ranking Model" involved recommending the extent to which the non-risk factors should be used in risk-ranking and decision-making. Finally, "Integration of Components 1 and 2" used the conclusions from steps 1 and 2 to help determine methods for future environmental decisions and priorities.[15]

IV. SELECTING PROBLEMS TO RANK

The risk ranking model used in the first U.S. EPA project developed a single list of thirty-one environmental problems, as shown in Table 1. Categories within the human health (cancer) and welfare columns are numerically ranked, with "1" having the highest risk. The human health (noncancer) ranking was done by labeling each category as high, medium, or low risk. Finally, the ecological risk type placed each risk category into one of six categories, with "category 1" having the greatest risk. Entries that are blank are environmental problems that were unranked for the specific risk type.

See id. The next step involved analyzing "budget cases" that group time-critical activities and other high-benefit and time-sensitive activities together. *See id.* Maximum and minimum budget cases were generated as well. *See id.* Step three involved evaluating budget cases. *See id.* The cost estimates used were for target-year costs, remaining costs, and future costs. *See id.* The budgets were scored on how well they met project objectives, and gross and net utilities of the benefits of each budget were determined. *See id.* The final step involved examining alternative budget allocations based on their score from the third step. *See id.*

15. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 67-69.

Table 1: Environmental Problems Selected for the 1987 EPA Project

CATEGORIES	HUMAN HEALTH (Cancer)	HUMAN HEALTH (Noncancer)	ECOLOGICAL	WELFARE
Worker Exposure (to chemicals)	1	High		Minor
Indoor Radon	1	Medium		20
Pesticide Residues (on foods)	3	High	Category 3	Minor
Indoor Air Pollutants (not radon)	4	High		Minor
Consumer Exposure to Chemicals	4	High		Minor
Hazardous/Toxic Air Pollutants	6	High	Category 4	23
Depletion of Stratospheric O_3	7	Medium	Category 1	6
Hazardous Waste Sites-Inactive (Superfund)	8	Low	Category 5	9
Drinking H_2O	9	High		19
Application of Pesticides	10	High	Category 3	Minor
Radiation Other Than Indoor Radon	11	Medium	Category 6	Minor
Other Pesticide Risks	12	Medium	Category 3	13
Hazardous Waste Sites-Active	13	Low	Category 6	11
Nonhazardous Waste Sites-Industrial	14	Medium	Category 5	15
New Toxic Chemicals	15	Unranked		Minor
Non-hazardous Waste Sites-Municipal	16	Medium	Category 5	10
Contaminated Sludge	17	Low	Category 5	22
Mining Waste	18	Low	Category 2	21
Release from Storage Tanks	19	Low	Category 6	16
Non-point Source Discharges to Surface Water	20	Medium	Category 3	2
Other Ground-water Contamination	21	Unranked	Category 5	Minor
Criteria Air Pollutants	22	High	Category 3	1
Direct Point Source Discharge to Surface Water	23	Low	Category 3	8
Indirect Point Source Discharge to Surface Water	24	Medium	Category 3	3
Accidental Releases-Toxics	25	High	Category 5	17
Accidental Releases-Oil Spills	26	Unranked	Category 5	18
Biotechnology		Unranked		14
CO_2 and Global Warming		Unranked	Category 1	5
Other Air Pollutants		Unranked		7
Discharges to Estuaries, Coastal Waters, Oceans	Unranked	Medium	Category 2	4
Discharge to Wetlands	Unranked	Low	Category 2	12

Information in table from U.S. EPA, *supra* note 7.

The 1987 EPA risk project appears to have suffered from double-counting because of the limited number of categories. Problems were divided such that they corresponded to current programs, statutes, and legislation, which resulted in individual areas having mixtures of sources, effects, and component problems.[16] Furthermore, heterogeneous mixtures of pollutants were compared to pollutant sources and pollutant receptors.[17] An example of such a situation involved health risks from inactive hazardous waste sites, which may also be counted under drinking water and hazardous air pollutants.

Despite the potential for double-counting, Morgan et al. support categorizing risks according to existing regulatory schemes. They argue that this will limit administrative costs by more directly matching the structure of the EPA.[18] Furthermore, even if this technique for choosing problem areas is flawed by double-counting, it has the advantage of expressing environmental problems in terms of how they are perceived by the public (as interconnected problems).[19] This could theoretically increase the ease with which the lay person can comprehend the project and make comments. It also, however, assumes that legislation is an accurate reflection of public will. Richard Minard argues that the political system is more responsive to the public than experts and so legislative priorities tend to follow the public's understanding of problems. He uses Superfund as an example where the most expensive program coincides with the public's concerns.[20] There is still, however, the possibility that public will has been distorted by Congress.

In addition to selecting categories, the source and type of agent and the source location should be considered.[21] Regardless of which combination of these criteria is used, problems should be identified such that the sizes of the categories are comparable. The 1987 EPA project recognized that the broader the problem category, the more

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16. *See* U.S. EPA, *supra* note 7, at 8-9.

17. *See* SCIENCE ADVISORY BD., *supra* note 1, at 7.

18. *See* M. Granger Morgan et al., *A Proposal for Ranking Risk within Federal Agencies*, *in* COMPARING ENVIRONMENTAL RISKS: TOOLS FOR SETTING GOVERNMENT PRIORITIES 111 (J. Clarence Davies ed., 1996).

19. *See* SCIENCE ADVISORY BD., *supra* note 1, at 12.

20. *See* Richard J. Minard, *CRA and the States: History, Politics, and Results*, *in* COMPARING ENVIRONMENTAL RISKS: TOOLS FOR SETTING GOVERNMENT PRIORITIES 23, 31 (J. Clarence Davies ed., 1996).

21. Morgan et al, *supra* note 18, at 126-129.

impacts it covers, potentially resulting in a higher ranking.[22] To control this variable, categories should be selected that have environmental impacts of roughly the same magnitude.

The 1990 project used primarily the same thirty-one problems identified in the 1987 project (Table 2). The more recent project, however, combined ecological health with welfare and this category contained an expanded list of problems. When ranking human health risks, the SAB only ranked those environmental problems for which there was adequate information to list them as high risks.

The California project created 3 environmental topic lists: "Environmental Releases to Media by Sources" (12 problems), "Environmental Health Stressors" (27 problems), and "Potential Threats to Environmental Integrity" (9 problems) (Table 3). These divisions were made to minimize confusion as to what each problem encompassed and to prevent double-counting.

Table 2: Environmental Problems Selected for the 1990 EPA Projects

RISKS TO THE NATURAL ECOLOGY AND HUMAN WELFARE	**HUMAN HEALTH CANCER AND NON-CANCER (ONLY 4 CATEGORIES WITH "RELATIVELY HIGH RISK" RANKING)**
Relatively High Risk Habitat Alteration and Destruction Species Destruction and Overall Loss of Biological Diversity Stratospheric Ozone Depletion Global Climate Change	***Ambient Air Pollutants*** Stationary Sources Mobile Sources
Medium Herbicides/Pesticides Toxics, Nutrient, Biochemical Oxygen Demand, Turbidity in Surface Waters Acid Deposition Airborne Toxics	***Worker Exposure to Chemicals*** Industry Agriculture
Low Oil Spills Groundwater Pollution Radionuclides Acid Runoff to Surface Waters Thermal Pollution	***Pollution Indoors*** Radon and Decay Products NO_2 Environmental Tobacco Smoke Consumer Products
	Pollutants in Drinking Water Lead Chloroform Microorganisms

Information in this table from SCIENCE ADVISORY BOARD, *supra* note 1, at 13-14.

22. SCIENCE ADVISORY BD., *supra* note 1, at 8.

Table 3: 1994 California: Environmental Topic Areas

LIST I. ENVIRONMENT RELEASES TO MEDIA BY SOURCES

Water	*Land*
Industrial Releases to Surface Water	Active Hazardous Waste Generators
Municipal Releases to Surface Water	Inactive Hazardous Waste Sites
Non-point Source Releases	Solid Waste Disposal Sites
Releases to Groundwater	Storage Tank Releases
	Treatment, Storage, and Disposal Facilities
Air	
Mobile Sources	
Residential and Consumer Product Sources	
Stationary and Commercial Area Sources	

LIST II. ENVIRONMENTAL HEALTH STRESSORS

Alteration of Aquatic Habitats	Ozone
Alteration of Terrestrial Habitats	Particulate Matter
Asbestos	Pesticides-Agricultural Use
Carbon Monoxide	Pesticides-Nonagricultural Use
Electromagnetic Fields	Radionuclides
Environmental Tobacco Smoke	Radon
Genetically Engineered Products or Organisms	SOx and NOx
	Stratospheric Ozone Depletors
Greenhouse Gases	Substances That Alter pH, Salinity, and Hardness
Inorganics	
Lead	Thermal Pollution
Microbiological Contamination	Total Suspended Solids, Biological Oxygen Demand, and Nutrients
New Chemicals	
Non-native Organisms	Volatile Organics
Oil/Petroleum	
Persistent/Bioaccumulative Organochlorines	

LIST III. POTENTIAL THREATS TO ENVIRONMENTAL INTEGRITY

Agricultural Practices	Recreational Practices
Commercial/Industrial Practices	Residential/Consumer Practices
Energy Management Practices	Transportation Systems
Municipal/Government Practices	Water Management Practices
Natural Resource Practices	

Source: California Comparative Risk Project, *supra* note 9, at 9.

V. Ranking Criteria

The projects varied in the usage of numerous factors to determine ranking. The most common criteria included economic analysis, public perception and inputs, consideration of risk-risk tradeoffs, spatial and temporal components, and risk types.

A. *Economics*

The 1987 EPA project did not consider economic or technical controllability of the risks, and therefore is closer to what might be considered risk ranking as opposed to priority ranking. Risk ranking tends to be considered just one of many tools used to facilitate the setting of priorities, while priority rankings can be used directly in making decisions.[23]

In contrast to its predecessor, the 1990 project performed an economic analysis. According to the SAB members, policy needs to be more focused on opportunities for environmental improvement than it has been in the past. This approach inherently means that the SAB considered the cost per unit of risk avoided in performing their 1990 risk ranking exercise. Considering optional strategies for reducing the major (high magnitude) risks was a separate objective from ranking.[24] Although project members relied on economic analysis to determine the most cost-effective risk reductions due to limits on resources, they criticized the usage of such economic methods as cost-benefit analysis because it undervalues natural resources. This under-valuation occurs in two ways; it relies on the values of public goods, which are under-priced in markets, and it ignores degradation as a "cost" in accounting and so underestimates costs and overestimates net benefits.[25]

Currently, the DOE project utilizes economic methods such as cost-benefit analysis under its third procedural step "evaluating alternative budget cases."[26]

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23. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 2; U.S. EPA, *supra* note 7, at 1-2.

24. *See* SCIENCE ADVISORY BD., *supra* note 1, at 5.

25. *See id*. at 25.

26. The Environmental Defense Fund (EDF) has criticized an approach used by the DOE: that is relying on the theory of maximizing utility. According to EDF, two budget cases may have a very small difference in overall relative utility where relatively little additional benefit is produced per additional level of funding. When a decision is made to select one budget case over the other, however, there could be dramatic consequences for the individual facilities affected because the optimal funding combination between sites could change. *See* James D. Werner, Natural Resources Defense Council, Comments on Behalf of the Natural Resources

The economic criteria utilized in the California project, as selected by the Economic Perspectives Committee, included economic efficiency, distributional impacts, uncertainty, and time considerations.[27] These criteria were used in determining the human welfare ranking, which is discussed later in this section.

B. *Public vs. Expert Perception of Risk*

In general, experts assess typical risks almost exclusively in terms of quantitative assessment of injuries, illness, or fatalities, and do not consider other parameters.[28] According to Margolis, however, there are two theories in addition to the traditional view that there are rival perceptions of risk and the meaning of dangerous. The first alternative theory is that the driving force involves deeper conflicts about "power and responsibility, human obligations to other humans and to nature," and hence, what purpose public policy is going to serve.[29] In other words, the overall conflict is about ideology as opposed to risk. The second theory is that the conflict is due to different perspectives of risk, but the driving force is a lack of trust by the public and the institutions trying to assure that danger is under control.[30]

By accounting for these qualitative factors, public participation can have drastic effects on rankings. Public perceptions may show, for example, that the value placed on one environmental goal exceeds that of other more tangible environmental goals.[31] Research done by Paul Slovik has shown that risks seen by experts as being the largest remaining environmental risks tended to be ranked low by the public.[32] Furthermore, previous studies show that even when experts and laypersons agree on the fatalities produced by a given environmental problem, they still disagree on the "degree of risk."

Defense Council and the Environmental Defense Fund Regarding the Proposed Department of Energy Priority System for Environmental Restoration 52-54 (Nov. 21, 1991) (on file with the Natural Resources Defense Council) (these comments were submitted in response to: Request for Public Review and Comment on a Preliminary Design Report: A Priority System for Environmental Restoration, 56 Fed. Reg. 44078 (1991)).

27. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 341-345.

28. *See* HOWARD MARGOLIS, DEALING WITH RISK: WHY THE PUBLIC AND EXPERTS DISAGREE ON ENVIRONMENTAL ISSUES 21 (1996).

29. *Id*.

30. *Id*.

31. *See* SCIENCE ADVISORY BD., *supra* note 1, at 12.

32. *See* Paul Slovik, *Perception of Risk*, 236 SCIENCE 280 (1987).

This discrepancy may be due to laypersons placing a greater emphasis on "catastrophic potential."[33]

The EPA project involved no public participation and included only those problems that have been neglected in the past, have increased in importance, or have only recently developed; it neglected the future and assumed the maintenance of existing environmental problems.[34] In fact, according to the 1987 EPA project, public perceptions were incorporated into the risk characterization by choosing problem categories that correspond to current legislation, as argued by Minard.[35]

The California project stressed the importance of public participation. As opposed to holding community meetings or distributing surveys, which are more common, the California project relied on roundtable discussions. Participants included representatives of business, local government, academia, labor organizations, and environmental groups. Three roundtables were held, all of which concluded that policymakers need to pay more attention to public participation.[36]

One reason the California project placed so much weight on public participation is that California chose to address the issue of environmental justice, which involves the efficiency of social choices about risk.[37] According to project members, there are two relevant guidelines to ensure environmental justice. First, public participation from diverse backgrounds must be incorporated into all agency activities. Second, environmental policies must consider the subpopulations that could be potentially affected, including race, socioeconomic status, vocation and location. The EPA, however, failed to consider the issue of environmental justice and equity.

To attain a true representation of social welfare benefits, the relative distribution of subpopulations should be determined. It is possible that only a select portion of the population is receiving benefits, suggesting that the optimal social welfare of the entire population is not being recognized. It is unclear why no other risk ranking exercise explicitly considered sensitive subpopulations and

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33. Baruch Fischhoff, *Risk Perception and Communication Unplugged: Twenty Years of Process*, 15 RISK ANALYSIS 137, 139 (1995).

34. *See* U.S. EPA, *supra* note 7, at 1-14.

35. *See How Safe is Safe Enough?, supra* note 3, at 79; Minard, *supra* note 20.

36. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 287-88.

37. *See id. See also* MARGOLIS, *supra* note 28.

environmental justice, especially when prominent studies on these issues began as early as 1971.[38]

One option to account for public risk perceptions involves addressing the acceptability of the risk. According to Baruch Fischhoff, this involves finding a publicly acceptable balance of personal risks and benefits. In general, individuals will be more willing to accept risk (and consequently rank it lower in a comparative risk analysis) if there are compensating benefits. Alternatively, they will be more likely to avoid risks if this is feasible at a reasonable cost. By taking data at the level of the individual as opposed to the society, subpopulations will be accounted for and equity will be much more likely.[39]

C. *Risk-Risk Tradeoffs*

An additional factor that should be considered in ranking risks is risk-risk tradeoffs. All actions have unintended as well as intended consequences. The assumption should not be made that by-product risks will be smaller than the risk the precautions are intended to correct.[40] The 1990 SAB project emphasizes the importance of considering risk tradeoffs by stating that future risk must be considered when relative risks are compared. "The risks entailed in postponing action can be greater than the risks entailed in taking inefficient or unnecessary action."[41] Current environmental problems often have a low-risk ranking because of effective regulatory control measures. Therefore, resource reallocation may result in increased risk in the areas affected by reduced regulation and may be seen as environmental injustice. Baruch Fischhoff's "acceptable risk" proposal would account for such potential tradeoffs by incorporating the potential changes in risks to individuals.[42]

In the California project, decision makers considered the costs of acting now as compared to the benefits of acting later, concluding that considering tradeoffs over a time-scale plays an important role in environmental decision-making.[43] Policy-makers should recognize

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38. *See generally* PETER S. MENELL AND RICHARD B. STEWART, ENVIRONMENTAL LAW AND POLICY (1994).

39. *See* Fischhoff, *supra* note 33, at 141.

40. *See* MARGOLIS, *supra* note 28.

41. SCIENCE ADVISORY BD., *supra* note 1, at 10.

42. *See* Fischhoff, *supra* note 33.

43. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 354.

and understand that both risk reduction and risk management involve tradeoffs that should be addressed explicitly.[44]

D. *Spatial and Temporal Factors*

Spatial and temporal factors were considered in the California and EPA projects. The 1987 EPA project looked at risks on a broader geographical and biospheric scale. It also focused only on current problems that existed at the 1987 levels of regulation and therefore has little applicability in predicting future problems.[45]

The 1990 SAB project, in contrast, emphasized the importance of temporal factors, concluding that the length of time over which the problem is caused, recognized, and mitigated should be considered. The 1990 project members concurred that the extent of the geographical area that is affected by a problem should be studied, and the range of human activities should be compared to the range of environment affected.[46]

The California project addressed the spatial issue by considering both individuals and populations when addressing human health risks.[47] As suggested by the 1990 committee, and in contrast to the 1987 EPA project, the California project concluded that comparative risk rankings should be reviewed on a regular basis to integrate more advanced scientific information and procedures.[48] This could aid in preventing predictable future human health impacts.

E. *Risk Types*

In addition to economic, public input, and tradeoff considerations, the projects compared different risk types. The 1987 EPA project looked at four types of risk for each environmental problem: ecological health, welfare, and human health (cancer and noncancer). All four types of risk were given the same level of importance.[49] This concept is noteworthy in that natural ecosystems are essential to human health and sustainability, economic growth, and that their intrinsic value should be accounted for.[50]

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44. *See id.* at 355.
45. *See* U.S. EPA, *supra* note 7, at 12-14.
46. SCIENCE ADVISORY BD., *supra* note 1, at 10.
47. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 73.
48. *Id.* at 96.
49. *See* U.S. EPA, *supra* note 7, at 5.
50. SCIENCE ADVISORY BD., *supra* note 1, at 9.

The 1990 project examined two types of risk: ecology and welfare, and human health. The combination of ecological health and welfare corresponds to its objective of merging the various risk rankings of the 1987 project.[51]

The California project had independent rankings for human health, ecosystems, and social welfare for each designated environmental problem.[52] Similar to the 1990 SAB project, it weighted them all equally.[53]

1. Human Health

The 1987 EPA exercise divided human health risks into cancer and noncancer. The cancer workgroup in the 1987 EPA project had two stages of actual ranking. The first ranking used general qualitative categories high, medium, and low. Following this initial level of ranking, an ordinal ranking was formed.[54] The non-cancer ranking involved a single ranking and found that ranking by individual versus population risks did not significantly alter the ranking. This distinction between cancer and noncancer human health risks reflected understandings about health effects.

The 1990 SAB project did not separate cancer and noncancer human health risks, focusing only on those problems ranked as having high risk. According to Davies, this particular distinction may place too much emphasis on the cancer endpoint (greater "dread" factor than noncancer) and may explain why more recent projects have not made this separation. Alternatively, he suggests that acute and chronic health effects should be considered separately.[55] This division, however, may have the same result as the previous categories if people instinctively fear one more than the other.

In ranking human health hazards in the California project, five steps were used, including the four conventional risk assessment steps (hazard identification, dose-response assessment, exposure assessment, and risk characterization)[56] and risk-ranking. The fifth component looked at how serious an individual problem is relative to

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51. *Id.* at 5.

52. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9.

53. *Id.*

54. U.S. EPA, *supra* note 7, at 21-27.

55. *See* J. Clarence Davies, *Ranking Risks: Some Key Choices*, *in* COMPARING ENVIRONMENTAL RISKS: TOOLS FOR SETTING GOVERNMENT PRIORITIES 9, 15 (J. Clarence Davies ed., 1996).

56. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 74.

the other selected problems.[57] Risk-ranking was performed by looking at the severity of the impact and the number of people affected. The risks posed by the environmental topic areas were then ranked as in the 1987 EPA exercise.[58] Cancer and noncancer risks were not distinguished.

2. Ecological Health

Ecological health was the second risk category studied. The 1987 EPA project considered 16 ecosystems.[59] The ecological work group also created 26 stress agent categories from the 16 ecosystems and developed geographical scales of potential ecological impact of environmental stressors, both of which were used in the final risk-ranking.[60] Finally, in assessing the ecological risk due to each stressor, the individual workgroup members considered the changes in the structure and functions of the ecosystems, the reversibility of the impact, and ecosystem recovery time for a reversible impact.[61] The EPA project appears, however, to neglect some vital information, including secondary as well as primary receptors, and the transportation of the stressor, which can influence the actual exposure levels.

The 1990 SAB exercise combined ecological and welfare risks into one ranking; specific parameters used by the project members to analyze the risks to ecosystems were not identified. The ranking for this project considered more than the 31 problem areas addressed by the 1987 EPA exercise.[62]

The Ecological Health Committee of the California project looked at "exposure pathways" to determine the relative severity of the individual risks.[63] The magnitude and severity of the impact of environmental problems were ranked as high, medium, or low by looking at their intensity (ecological severity), extent (proportion of

57. *Id.* at 83.

58. *See* U.S. EPA, *supra* note 7, at 21-42.

59. *Id*. at 45. The 1987 EPA project examined 4 freshwater, 3 marine and estuarine, 4 wetland, and 5 terrestrial ecosystems. *Id.*

60. *Id.*

61. *Id.* at 46.

62. *See* SCIENCE ADVISORY BD., *supra* note 1, at 4.

63. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 142. In order to analyze the complete pathway, the activity (transportation) of the hazard, the specific stressor, the medium, receptor(s), and effects were all considered. *Id.*

the ecosystem affected), reversibility (permanence), and probability/uncertainty (level of certainty the event will occur).[64]

3. Welfare

The final risk category studied was social welfare. The 1987 EPA project required that where possible, damages should be estimated in monetary terms (1986 dollars) to assure a common basis for comparison.[65] In addition, and perhaps surprisingly, this workgroup also evaluated current and future environmental effects. According to the project goal, only risks present in 1987 were to be determined. Therefore, the workgroup must have assumed that the 1987 levels of control would continue and that no new problems would appear.

In addition to performing the social welfare analysis (primarily economic impacts) done by traditional comparative risk projects, the California project looked at mental health, aesthetics, equity, and future well-being.[66]

V. RANKINGS

A. *Aggregate Rankings*

The 1987 EPA project found no environmental problems consistently ranking high in all four risk types; only criteria air pollutants, stratospheric ozone depletion, pesticide residues on food and other pesticide risks ranked high in three out of four risk types, or medium in all four.[67] Hazardous air pollutants, indoor radon, indoor air pollution other than radon, pesticide application, exposure to consumer products and worker exposure to chemicals ranked relatively high in cancer and noncancer, while point and non-point sources of surface water pollution, global warming, physical alterations of aquatic habitats and mining waste ranked high in both

64. *Id.* at 144-45.

65. *See* U.S. EPA, *supra* note 7, at 51.

66. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 221-222. The Social Welfare Committee used "optimal social welfare" as a standard for analysis. They used the following eight criteria to evaluate the relative risk of each environmental problem: the number of people exposed, the number of people impacted, the severity of the impact, the irreversibility of the impact, the level of involuntary exposure, uneven distribution between subpopulations, the potential for catastrophic impact, and the level or lack of detectability. *Id.* at 222-223.

67. *See* U.S. EPA, *supra* note 7, at 94.

ecological health and welfare risks. Groundwater was consistently ranked medium or low for all risk types.[68]

The 1990 SAB project ranked global environmental problems as high under the combined category of natural ecology and human welfare, but no global problems were ranked as high priority under human health.[69] Furthermore, its ecological/welfare rankings agree with the ecological rankings of the 1987 EPA project and with the welfare rankings of the 1994 California project, emphasizing the importance of combining the rankings of individual risk types.[70] Those problems that were considered to be high human health risks included ambient air pollutants, worker exposure to chemicals, indoor pollution, and pollutants in drinking water.[71]

The 1994 California project ranked ozone as a high priority in all three risk types, while alteration of habitats, environmental tobacco smoke, PM, radionuclides and inorganics were ranked high for two risk types.[72]

In addition to being ranked high under multiple risk types within the same project, some problems were similarly ranked between projects. Pesticides (residues on food, worker exposure, other risks), air (media), global warming (climate change) and stratospheric ozone depletion were all ranked high in at least one risk type in each project. Radon was considered a high risk by both the California[73] and SAB projects[74] while the EPA and SAB gave worker and consumer exposures high rankings[75]; groundwater was ranked high by California and low by the EPA and SAB[76]. Finally, drinking water and worker and consumer exposures were high according to both the EPA and SAB, while California did not even include them in its list of environmental problems.[77]

68. *Id.*

69. *See* SCIENCE ADVISORY BD., *supra* note 1, at 13-14.

70. *See* U.S. EPA, *supra* note 7, at 48-49; SCIENCE ADVISORY BD., *supra* note 1, at 13-14; CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 213.

71. *See* SCIENCE ADVISORY BD., *supra* note 1, at 14.

72. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 32.

73. *Id.*

74. SCIENCE ADVISORY BD., *supra* note 1, at 14.

75. *See* U.S. EPA, *supra* note 7, at 89-90; SCIENCE ADVISORY BD., *supra* note 1, at 14.

76. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 147, 151-53; U.S. EPA, *supra* note 7, at 83.; SCIENCE ADVISORY BD., *supra* note 1, at 13.

77. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 143; U.S. EPA, *supra* note 7, at 72, 89-90; SCIENCE ADVISORY BD., *supra* note 1, at 14.

B. *Human Health*

The 1987 EPA cancer group ranked the problems based primarily on risks to populations. Although risk at the individual level was not the basis for the rankings, the group chose to note those problems with very high potential risks to individuals.[78] According to the rankings shown in Table 1 air is the medium of greatest concern, especially indoor air pollution, hazardous/toxic air pollutants and criteria air pollutants.

The 1987 EPA noncancer group combined the following three scores: severity of endpoints, the exposed population, and the likelihood of an effect given an exposure.[79] The non-cancer scores in the 1987 EPA project were shown to be highly dependent on the severity of the health endpoints, the size of the population exposed, and the potency of the given substance.[80]

The 1990 SAB project combined cancer and noncancer human health risks and identified only those areas where existing data indicated risks could be relatively high.[81] It ranked problems categorically as opposed to numerically, as did the California project.[82] The results show that air was the medium of greatest concern.[83] Although both the EPA and SAB projects ranked worker and consumer exposures high, the 1987 project ranked worker exposure slightly higher numerically.[84]

The results in Table 4 show the ranking results of "environmental health stressors" presented in the California risk project.[85] It was observed in this project that the extent and severity of noncancer adverse effects significantly affected the rankings. For instance, particulate matter, ozone, environmental tobacco smoke, and lead, resulting in cardiovascular disease, developmental or neurological toxicity, and increased mortality, were considered high

78. U.S. EPA, *supra* note 7, at 17.

79. *See id*. at 39-40. In the 1987 EPA project, problems such as hazardous air pollutants, drinking water, worker and consumer exposures moved between medium and high risk categories based on different combinations of the three criteria, and were designated as high risks in the published analysis. *See id.* at 58-90.

80. *See id*.

81. *See* SCIENCE ADVISORY BD., *supra* note 1, at 13; Table 2, *supra*.

82. The 1990 EPA project members determined that the available data was insufficient for an ordinal ranking. *See How Safe is Safe Enough?, supra* note 3, at 91.

83. *See* SCIENCE ADVISORY BD., *supra* note 1, at 14.

84. *See* U.S. EPA, *supra* note 7, at 89-90. This may be due to the high level of risk that employees are exposed to in the working environment.

85. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 32.

risk.[86] Like the 1987 EPA project, air is the medium of greatest concern.[87]

Table 4: 1994 California: Combined Results of Human Health Risk-rankings of Environmental Releases to Media by Sources and Health Stressors

CATEGORY	HUMAN HEALTH (CANCER AND NONCANCER)	SOCIAL WELFARE	ECOLOGICAL HEALTH
Alteration of Aquatic Habitats		High	High
Alteration of Terrestrial Habitats		High	High
Environmental Tobacco Smoke	High	High	
Greenhouse Gases		High	Medium
Lead	Medium	High	Medium
Ozone	High	High	High
Particulate Matter	High	High	Low
Pesticides-Agricultural use	Medium	High	Medium
Pesticides-Non-agricultural Use	Medium	High	Medium
Radionuclides	High (natural sources) Low (anthropocentric sources)	High	
Stratospheric O_3 Depletion		High	
Volatile Organics	High	High	Low
Asbestos		Medium	
Inorganics	High	Medium	High
Microbiological Contaminants	Medium	Medium	Low
Non-native Organisms		Medium	High
Oil and Petroleum Production		Medium	Medium
Persistent Organochlorines	High	Medium	Medium
Radon	High	Medium	
SO_x and No_x	Low	Medium	High
Alteration of Acidity, Salinity or Hardness of Water	Low	Low	Medium
Carbon Monoxide	Medium	Low	
Thermal Pollution		Low	
Total Suspended Solids, Biological O_2 Demand, or Nutrients in Water	Low	Low	Medium

Table modified from CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 32.

86. *See id.* at 85.
87. *See id.*

A majority of the high-ranked risks involve such susceptible subpopulations as children, minorities, those with preexisting medical conditions, and those who have unusually high exposures due to vocation or location.[88] It was also discovered that California has geographical "hot spots" such as inner city neighborhoods. Many such areas do not have adequate political representation thus emphasizing the importance of including public input. The California project neglected such environmental problems as waste sites and drinking water, which were ranked high in the EPA projects. This suggests that California should adjust its problem categories.

C. *Ecological Health*

The 1987 EPA project looked at the impacts of twenty-two problems on a set of ecosystems and on broader geographical and biosphere scales.[89] It ignored five problems that were judged as presenting little or no ecological risk.[90] As previously discussed, the 1990 SAB project combined ecological and welfare risks into a single ranking.[91] Like the health ranking, this one is also categorical. Although there is as much uncertainty in this ranking as those for the other projects, it should be noted that the high ranking of global warming, depletion of stratospheric ozone, discharges to estuaries, coastal waters and oceans, and discharges to wetlands will probably not change regardless of additional scientific information.[92] The 1987 EPA project ranked global concerns such as stratospheric ozone depletion and global warming as high priorities.[93]

The 1990 project gave high priority to those ranked high or medium by both the 1987 EPA and California projects including habitat alterations and global climate change.[94] Because the 1990 SAB project combined ecological with social welfare, however, it may not be accurate to directly compare it with the results of the other projects.

Reporting the ecological risk-rankings in the California risk project was considerably more difficult than reporting those of

88. *See id*. at 86.

89. *See* U.S. EPA, *supra* note 7, at 44.

90. *See id.* at 44.

91. *See* discussion *supra*, Part V. E. 2.

92. *See* U.S. EPA, *supra* note 7, at 64-65, 70-71. This is a consequence of the large geographic scale and long mitigation time scale that are associated with each. *See id.*

93. *See* Table 1, *supra*.

94. *See* Table 2, *supra*.

human health because a "translation" was involved.[95] The Ecological Health Committee initially presented a relative ranking of aggregate threats and then translated this into an ecological health risk-ranking of environmental health stressors.[96] As in the human health ranking, the Ecological Health Committee ranked the risk categories as high, medium or low.[97] For each aggregate environmental threat, the most sensitive biological receptor was identified.[98] Habitat alterations, including the introduction of non-native species, were ranked much higher than global impacts or water quality.[99] These are also very different rankings from that of human health, which tended to give man-made substances highest priority.[100]

D. *Welfare*

The welfare rankings for the 1987 EPA project are shown in Table 1. Numerous problems were encountered in this ranking system. The choice of category division was shown to affect the ranking, as discussed above.[101]

The project members discussed their difficulty in distinguishing welfare effects from the health and ecosystem effects, an obstacle experienced in performing all the projects.[102] Because of the interdependence of these three effects categories, there is likely much double counting. The welfare rankings in this project place the

95. CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 169-70.

96. *See* Table 4, *supra*; CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 139-202.

97. *See id*. at 146-47.

98. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 142-44. It is unclear if the actual receptors involved influenced the relative ranking of the environmental threat. The following are some examples of high ranked aggregate threats and their corresponding biological receptors: atmospheric oxidants-coniferous forests; introduced species-geographically restricted or specialized native species; mining waste and drainage-river communities/riparian communities; urban runoff-aquatic populations near large cities; water diversions-aquatic and terrestrial estuarine communities/river communities. *See id*. at 149-61, 187 Table 3.

99. This may reflect the aesthetic value humans place on the natural environment.

100. *See* CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 85-89, 185-86 Table 2.

101. *See* U.S. EPA, *supra* note 7, 51-54. For example, the welfare effects from pesticides were divided between "Nonpoint Source Discharges to Surface Waters", "To estuaries, coastal waters, and oceans from all sources, and "Other Pesticide Risks." *Id*. at 51-52. The result is that this third category is ranked lower than if all pesticide effects were under one category. *Id*. at 51-52.

102. *Id*. at 51-54. Specifically, something which is initially a welfare effect due to a loss in commercial value could rapidly become a health effect as people respond to the potential for adverse impacts. *See id.*

greatest concern on discharges to water and problems that are of a global magnitude.[103]

It is difficult to directly compare the results of the 1990 SAB project to only the ecological or human welfare rankings of the other projects. It should be noted, however, that this project assigned relatively high rankings to habitat destruction and problems that will have global impacts.

The social welfare ranking of "environmental health stressors" from the California project ranked both habitat alterations and global problems as great concerns,[104] and strongly correlates with the results of the 1990 EPA project.[105]

VII. RECOMMENDATIONS FOR PROJECTS

A variety of factors must be utilized to successfully complete a risk ranking project. A minimum of economic analysis, public participation, and spatial and temporal factors must be considered as well, in order to decide risk priorities. Some suggestions have included using Contingent Valuation Surveys because market prices often undervalue environmental resources. In addition, the usage of a publicly acceptable balance of personal risks and benefits has been suggested.[106] Public participation may be incorporated by holding hearings or discussions, and can mitigate environmental injustices. It is generally accepted that risks need to be considered on broad geographic scales and should include potential future problems.

Future projects should integrate all information into a single risk ranking. By having numerous individual rankings, previous projects have had no overall ranking and therefore, the comparative risk analysis may not serve its intended purpose. Furthermore, it may cause individual problems to spread across different risk rankings with their full risk impact never being recognized. Finally, because of the limited number of categories, it is difficult to compare different problem categories unless all the rankings are integrated.

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103. *See* Table 1, *supra*.

104. CALIFORNIA COMPARATIVE RISK PROJECT, *supra* note 9, at 213 Table 1, 227, 229.

105. *See* Table 4, *supra*.

106. *See* Fischhoff, *supra* note 33, at 141-142.