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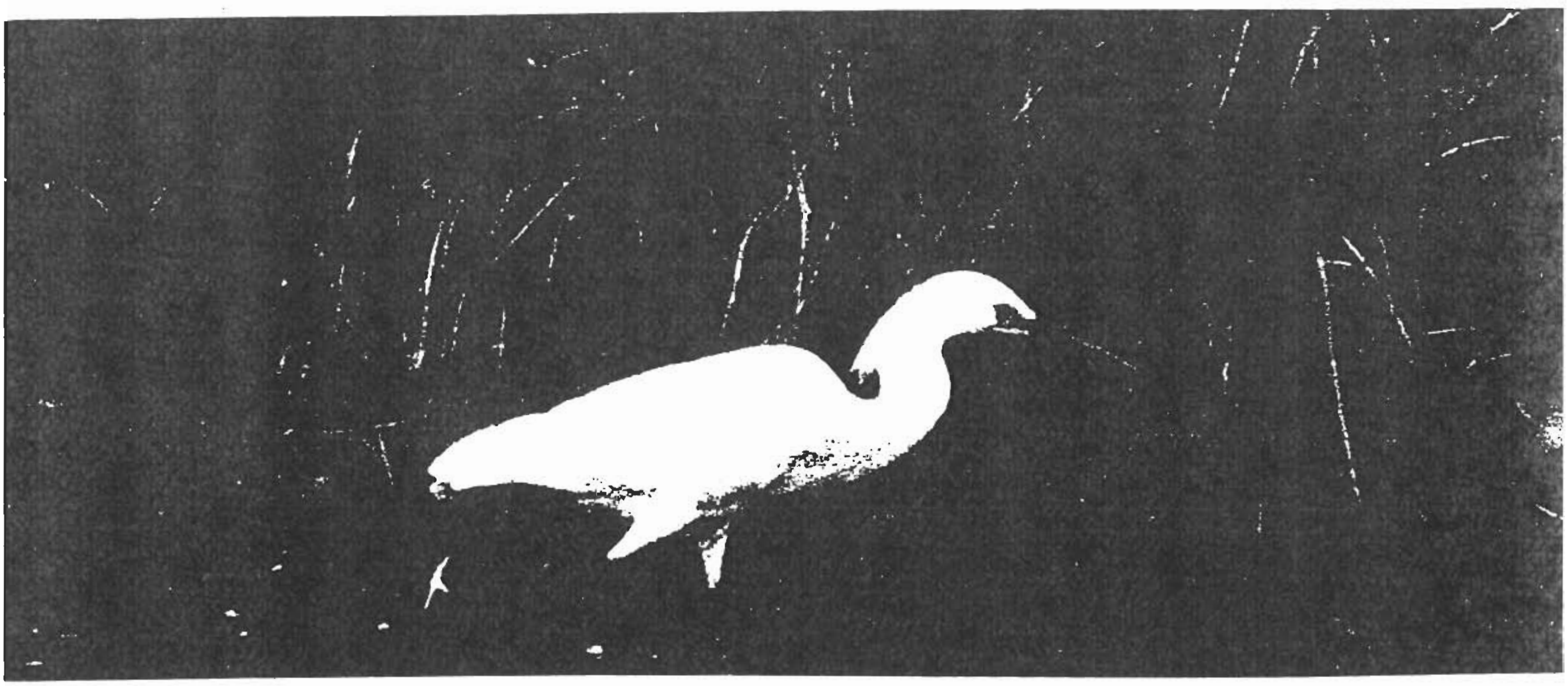
Appendix C: Strategies for Ecological Effects Research



Report of the Subcommittee on Ecological Effects

Research Strategies Committee

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**** Table of Contents ****

1.0 EXECUTIVE SUMMARY

1.1 The Role of Ecological Effects Research at EPA

EPA was created in 1970 specifically as the regulatory agency responsible for protecting the environment. The 1970 reorganization creating EPA transferred responsibilities for conducting research on ecosystems from the Council on Environmental Quality (CEQ) to EPA. In this capacity EPA has both executive and legislative mandates to conduct ecological research upon which other responsibilities related to its mission depend. Congress has enacted 15 statutes, 11 enforced by EPA, that are aimed at protecting the environment from anthropogenic insult, such as those from chemicals, solid waste and other toxic substances. Virtually all of the environmental statutes enacted by Congress require EPA to protect ecological values, ultimately requiring preparation of ecological risk assessments. Among the important components of the environment to be protected are both biotic and abiotic components ranging from endangered species to biogeochemical cycling.

1.2 Status of Ecological Effects Research

Several other Federal agencies conduct or support ecological research related to their individual missions. Much of this ecological research contributes information that is important to EPA's mission and responsibilities; however, this research falls short of providing a focused and systematic answer to many of EPA's needs.

EPA's ecological research program has been constrained by limited resources. Therefore, the preponderance of the Agency's research effort has been concerned with questions that directly support immediate decision-making activities. Short-term decisions have dominated and defined research needs; for example, the development of single-species, toxicological test methods for implementing the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Efforts of lesser priority have generated tools for predicting acute toxicity based on chemical structure, and methods to extrapolate from acute to chronic effects or from species to species, especially in aquatic communities.

1.3 Needs and Opportunities for Strategic Ecological Effects Research

Recognition is growing in the U.S. and elsewhere that the scope of ecological research must be broadened to accommodate the spectrum of decisions concerning environmental quality that must be made at present. A broadened scope of research is also needed to provide for acceptable environmental conditions in the future. Current, identifiable limitations of scope unequivocally demonstrate that a full recognition of the need for ecological risk assessment has not been attained. Also, the structure of ecological risk assessment has not incorporated current ecological knowledge and concepts. In particular, critical areas of resource management, population theory, and knowledge of the mechanisms of ecosystem processes need to be incorporated into a research effort that is directed towards ecological risk analysis.

Broadening the scope of ecological research is necessary to provide the opportunity for strategic ecological effects research. Building on past studies of effects on individual organisms, effects on appropriate populations of organisms, interactions in multiple media and effects on communities or ecosystems, new studies are needed to provide a comprehensive understanding of environmental processes and the consequences of human activities. Studies of these ecologically realistic effects must relate the impacts of pollution to key characteristics of ecosystem function, such as physical habitat loss or species diversity. General risk assessment guidelines should emphasize investigating and assessing effects that are cumulative, long-term, and of regional or global scale. Research pathways that lead toward answers to these questions will provide the understanding necessary to anticipate and evaluate both the magnitude and consequence of ecological effects.

To build appropriate methodologies, a knowledge base, and a data base for evaluating ecological risks and effects, and to provide the information required to meet the overall needs of the Agency, a research strategy with the following four components is recommended:

1.3.1 Assessing risk to ecological systems

Interrelated research activities are required to refine and improve environmental risk assessment procedures including: a) identifying appropriate protocols, b) identifying meaningful endpoints, c) characterizing and quantifying exposures, and d) analyzing and quantifying uncertainty. These refinements should be applied as terms in and as structures of models, when determining appropriate assumptions or conditions of application, and via the parameters to be measured to perform environmental risk assessments.

1.3.2 Defining the status of ecological systems

Understanding the degree to which the quality of the environment may decline as a result of human activities or improve as a result of environmental management and remediation activities depends upon a valid and accurate assessment of environmental characteristics. Ecosystem status measurements and analyses of these data provide the fundamental information that is needed to characterize and understand the environmental resource that EPA is charged with protecting.

1.3.3 Detecting trends and changes in ecological systems

Monitoring allows detection and quantification of changes in specific parameters that are judged to be either critical in themselves or that serve as indicators of changes. Monitor-ing is also necessary to assess the effectiveness of environmental management and mitigation practices, and to provide future generations with reference statistics.

1.3.4 Predicting changes in ecological systems

Developing new and expanded predictive methods and assessment techniques requires considerations of complexities, such as impacts of indirect and long-term effects, responses to multiple insults, variability between ecosystems, and differences in spatial and temporal scale. Developing a predictive capability will require predictive studies, experiments in natural ecosystems and the development and validation of models.

2.0 INTRODUCTION: ECOLOGICAL RESEARCH AND EPA'S MISSION

2.1 EPA's responsibilities in ecological assessment and research

EPA was created in 1970 specifically as the regulatory agency responsible for protecting the environment. In this capacity EPA has both executive and legislative mandates to conduct ecological research in support of other aspects of its mission, responsibilities transferred to EPA from CEQ. Congress has enacted 15 statutes, 11 enforced by EPA, that are aimed at protecting the environment from anthropogenic insults such as those from chemicals, solid waste and other toxic substances. Many of the environmental statutes enacted by the Congress explicitly require EPA or other agencies to prepare ecological risk assessments. Appendix I identifies these statutes and their provisions. Aspects of the environment to be protected include fish and wildlife resources, food webs serving human consumption, aesthetic and recreational values, and rare and endangered species. EPA's mission also entails maintaining basic biotic and abiotic life support systems, such as long-term productivity of aquatic and terrestrial ecosystems and biogeochemical cycling.

The Agency's past emphasis with respect to anthropogenic stresses has been on human health. This emphasis has translated into a capability to perform human health risk assessments. This capability far surpasses the Agency's ability to perform environmental risk assessments, primarily due to our relative lack of knowledge of effects other than those on human health.

The importance of maintaining viable, healthy ecosystems for human welfare and health is increasingly recognized by the public and private sectors. In a recently completed exploratory review of environmental problems, EPA identified thirty-one major environmental problem areas and characterized them in terms of their relative importance. Twenty-two of these problem areas were identified as important because of effects mediated by ecological impacts [1]. These problem areas involve 16 particular types of ecological systems; some involve entire geographic regions, while others represent cases where the entire biosphere is at risk.

2.2 Relationship of EPA's Ecological Research Program to those of other Agencies

A number of other Federal agencies conduct or support ecological research, including the Fish and Wildlife Service (FWS/Department of the Interior), the Forest Service (FS/U.S. Department of Agriculture), the National Oceanic and Atmospheric Administration (NOAA/Department of Commerce), the Department of Defense, the Department of Energy, and the Bureau of Land Management. Respective ecological research programs are related to the statutory missions of those agencies. More fundamental research in ecology is supported principally by the National Science Foundation (NSF).

While much of the ecological research conducted by other agencies contributes information that is important to EPA's mission, it falls short of providing a focused and systematic answer to many of EPA's needs. Since each Agency has a specific mission, it is not surprising that many direct concerns to EPA may not be addressed at all by the other agencies. The result is that no one agency is collecting, integrating and synthesizing ecological information in a way that supports EPA's need to measure the status of ecological systems and to anticipate and detect potentially unfavorable trends and changes.

Of course, EPA should keep abreast of related ecological research programs at sister Federal agencies, and special efforts should be made to encourage coordinated research wherever feasibility and efficiency warrant. Such coordination will complement and enhance the impact of the Agency's own strong, independent effort, which is necessary to meet its specific goals and obligations.

2.3 Mission of an ecological research program for EPA

In response to limited resources, EPA has concentrated its research effort on immediate and obvious questions that directly support decision-making. Of necessity, past research has supported decisions needed in the short-term. For example, research efforts have focused on single-species, rapid toxicity test methods for regulatory permitting processes. These efforts shorten the time and expense of testing at the sacrifice of correctly identifying the hazards of slow acting toxicants or those that will cause problems by indirect mechanisms.

There is growing recognition that the scope of research must broaden. This recognition is prompted, for example, by cascading effects seen in response to acid deposition, and in far-reaching effects seen as a result of stratospheric ozone depletion. A broadened scope must accommodate the full spectrum of decision-making, in both the near- and long-term. The ecological effects of complex mixtures (as opposed to single chemicals) are now being considered, and risk assessment methods are being explored that can be applied at the population, community and ecosystem levels, as well as the single organism/species level. Regional and global scale, as well as long-term ecological problems are being given increased attention, although little administrative or budgetary support is apparent.

Some ongoing EPA research programs do reflect this broader emphasis and they include investigations into effects of acid deposition, protection of wetlands, effects of global climate change, and questions of microbial ecology/biotechnology. Even in these forward-looking programs, there are identifiable limitations of scope which suggest that a full appreciation of the needs for ecological risk assessment has not been attained. With the exception of newer approaches described above much of the research involves testing for toxic effects on ecological components, rather than considering the ecological system as a whole. The focus of research programs generally remains on effects of individual pollutants on individual organisms, although some projects take a multimedia, community assessment approach. Additionally, focus is typically placed on knowing the pollutant, rather than on knowing the environment that we seek to protect.

The Subcommittee on Ecological Effects envisions three main goals for EPA's ecological research program. They are, in order of priority:

a. Providing a strong scientific basis for ecological considerations in Agency decision making.

b. Moving EPA into a clear leadership position among agencies with environmental responsibility.

c. Developing the organizational and intellectual capabilities that will enable EPA to advance ecological science.

2.3.1 Providing a strong scientific basis for considerations in Agency decision-making

In planning and conducting ecological research, EPA mst remain continually aware of the need to integrate research findings and assessments into the regulatory responsi-bilities which are manifest as its policy framework. This framework, derived from current statutes and regulations, generally consist of a set of linked questions, the answers to which should develop from ecological considerations. These key questions include:

a. Status

How extensive is ecosystem change, and how does it affect the human component of the ecosystem, e.g. human values and activities?

b. Causality

What are the relationships between environmental stresses and the effects observed?

c. Risk

What consequences are posed to ecosystems from pollutant stresses?

d. Mitigation

What ecological improvements can be brought about by various choices among options for mitigating environmental impact and at what additional or alternative ecosystem risk?

e. Recovery

What rate and degree of ecosystem recovery can be anticipated as pollutant stresses are reduced?

f. Prognosis

What is the probability, source and magnitude of ecological effects anticipated in the future?

Simple consideration of direct effects (such as single species toxicity) will not suffice to provide adequate answers for these questions. Therefore, EPA should develop the capability to address broader ecological questions. Such capability will allow EPA to progress towards solutions to the 22 ecological problems that the Agency has identified [1].

The incorporation of ecological data into the decision-making and the regulatory process can enhance the Agency's performance and the safety of the environment by:

a. Identifying reasonable goals and facilitating determination of the degree to which environmental goals are being met.

b. Providing a sound scientific basis for setting priorities, ranking environmental problems and allocating resources.

c. Optimizing selection of methods for preventing, detecting, solving or mitigating environmental problems.

d. Expediting the clear communication and integration of research results to EPA, state and local governments, and the public.

2.3.2 Moving EPA into a leadership position among agencies with environmental responsibility

At the moment, no one agency has undertaken the task of compiling and making available the full spectrum of environmental data or of coordinating the plans for gathering needed data. There is an obvious need for centralized coordination, and EPA is the logical choice for the role, both in terms of having the greatest needs for this information and the breadth and availability of expertise in matters of environmental quality.

2.3.3 Developing the organizational and intellectual capabilities that will enable EPA to advance ecological science

The answers to many of the questions that EPA must address are likely to require the development of new theories and concepts, as well as simply new data. To ensure the growth of that knowledge base, it is necessary for EPA to participate in the progress of the science of ecology.

The Federal support of fundamental ecological research is primarily the province of NSF. However, NSF's research program is primarily predicated on the interests of the Nation's researchers, and there is no guarantee of complete congruence between the needs of EPA and the priorities of the scientific community at any particular time. Thus, to encourage development of ecological science in the direction it requires, EPA should allocate a reasonable fraction of its research effort to fundamental research, particularly in areas where the scientific community is not adequately addressing the needs of EPA.

3.0 RISK ASSESSMENT AS A UNIFYING GOAL FOR THE RESEARCH PROGRAM

3.1 What is an ecological risk assessment?

3.1.1 Definition

An ecological risk assessment is an estimate of the likelihood severity and extent of ecological effects associated with an exposure to an anthropogenic agent or a perturbational change, in which the risk estimate is stated in probabilistic terms that reflect the degree of certainty.

The steps in ecological risk assessment may include:

a. Hazard identification

Demonstrating the plausibility of a specific adverse environmental effect and the mechanism linking the effect to a particular human action.

b. Determination of the population at risk

Identifying the extent of the landscape that can potentially be affected.

c. Source inventory

Determining the potential intensity of the activity that generates the factor creating a hazard usually via an environmental survey.

d. Exposure assessment

Measuring the ambient intensity of the causal factor adjusted for transport, dispersal ecological interactions and vulnerability patterns which modulate the effective dose.

e. Dose-response determination

Relating the magnitude of the effect and the intensity of the exposure to the causal factor.

f. Risk characterization

Putting together all of the pieces to obtain an estimate of the probability distribution of a range of outcomes.

g. Quantification of uncertainty

Documenting the uncertainty about the estimate due to potential uncertainties in measurement and prediction through the process.

3.1.2 Benefits

Risk assessment is simply a systematic and formal application of all the information that is available for predicting outcomes under actual or hypothetical conditions. The outcome is expressed as the probability of some unit of "effect" and the hypothetical conditions have to do with alternatives about which decisions can be made. The objective is to process information in such a way that the most accurate prediction possible is provided. The predictions must be suitable for deciding among alternatives, while keeping track of the degree of uncertainty so that the decision-maker can have some indication of how firm the prediction is. The formal methodology of risk assessment accomplishes this objective in a comprehensive and logical manner.

Risk assessments are designed to promote better decisions. A focused ecological research program can provide for more certainty in environmental risk assessments, both in terms of effect and assumptions, thereby offering three major types of benefits:

a. The quality of the advice given in support of decisions will improve, so that subsequent environmental management and regulations will be improved.

b. The potential for making more accurate predictions will be enhanced. Predictions can trigger preventive action, reducing the need for costly and after-the-fact mitigation, recovery and clean-up programs.

c. Risk estimates will be more reflective of actual risk posed allowing for narrower "margins of safety" and potentially less restrictive regulation.

The accumulated procedures used to assess risk have a modest track record in evaluating human health questions related to environmental pollutants, but have been applied more tentatively to ecological questions. Given the need for ecological risk assessment at EPA, concerted emphasis should be placed on vigorous development of ecological risk assessment methods.

3.2 Shortcomings with some present approaches to ecological risk assessment

Present ecological risk assessment practices commonly fall short of their potential in three ways:

a. The risk assessment may fail to consider all the ramifications in a complex causal network, so that it presents an assessment of only some of the risks.

b. The risk assessment may fail to provide adequate estimates of uncertainty, so the user has little or no basis for evaluating its results compared to those of any other prediction methodology.

c. The knowledge base and data base may be so weak that the uncertainty estimate associated with the risk assessment renders the conclusion tentative, unusable or indefensible.

If the measured uncertainty is enormous, that fact is extremely important. In such cases the decision-maker (and the affected constituency) need to be aware of the magnitude of the uncertainty, both to allow for appropriate caution in the decision and to document the need for improved information.

3.3 Present approaches to environmental risk assessment

The field of ecological risk assessment continues to evolve as the method is applied to a variety of environmental problems. Such applications have served to identify areas of uncertainty in risk assessment and aid in defining areas for additional research.

EPA's Ecological Risk Assessment Program has the primary goal of formalizing and systematizing scientific knowledge of ecological risks in order to provide both guidance and models for decision-makers. For example, in EPA's Office of Pesticides and Toxic Substances environmental risk assessments assist decision-makers in making at least two kinds of decisions:

a. Predicting environmental impacts without access to any observational data (the Premanufacturing Notification requirement of the Toxic Substances Control Act)

b. Extrapolating observed behaviors from single ecosystems (at best) to all other ecosystems that conceivably might become exposed through, for example, the expanded use of pesticides.

Because of experimental and observational tractability, most of EPA's ecological risk assessment approaches have focused at the level of single organisms. These techniques have proven valuable, especially for certain species about which much is known, but serious uncertainties exist in our ability to assess broader ecological risk, which impact on the quality of decisions. When risk assessments are based just on extrapolation from acute or chronic dose responses of individual organisms, potentially important indirect effects can be missed. Current single-species tests can indicate reductions in life span, health, and reproductive rate. However, in complex communities, populations under stress may increase because of reduced competition or prediction. An example of such indirect effects occurs with algae blooms, which may occur after insecticide treatments have removed the consumers that normally keep the algae population at lower levels of abundance.

Overall, these efforts indicate a serious interest in ecological risk assessment at EPA, but the full potential of ecological risk assessment is not being realized, both for lack of an agreed upon systematic methodology for a complete risk assessment and a lack of fundamental knowledge in the science of ecology.

3.4 Information needs for ecological risk assessment

3.4.1 The endpoint problem

There are no obvious ecological equivalents of "human cancer rate" or "reactor-core meltdown probability" to serve as the common currency for a quantitative statement of the magnitude of the outcome where risk is of concern. This common currency is sometimes called the "endpoint". For the purpose of communication, it may be necessary to find an analog to the situation in human health risk assessment; however, non-health ecological concerns are more difficult to reduce to a simple one-dimensional functions. There are numerous types of ecological effects, many of which are not interconvertible or self-evident in terms of environmental quality or human welfare. These include:

a. Effects on the biosphere as a life support system

b. Effects on agricultural productivity

c. Effects on productivity of harvested wild lands

d. Effects on aesthetics/amenity functions

e. Effects on endangered species

f. Symbolic indices of our care for the environment.

To the extent that these endpoints are genuine matters of concern for some substantial constituency, they are all legitimate endpoints. However, they are qualitatively diverse, difficult to compare or relate quantitatively, and not recognized by a universal constituency. To improve the risk assessment process, meaningful endpoints that relate to causal factors must be found.

3.4.2 Ecological dose-response relationships

Dose-response relationships are not only applicable to toxicity testing of individuals but can also be extended to the measurement of responses at the population, community, and ecosystem levels. Often, the dose-response information is based on the results of controlled laboratory experiments. But simplified conditions in laboratory tests (and some modest scale field plot tests) may not adequately mimic behavior of the real system. Discrepancies and inconsistencies arise due to effects of scale, complexity, boundary processes, and missing or unrecognized factors. Further, the available laboratory data are usually quite restricted with respect to the number of species, life cycle stages, and genetic strains studied, and frequently ignore effects of multiple stresses, and population, community, and ecosystem level effects. For these reasons, it is essential that dose-response relationships used in risk assessments be verified in intact systems.

Unfortunately, much of the available dose-response data represent those systems that have been considered scientifically interesting and convenient, so this "sample" cannot be counted on to represent the real distribution of possibilities. Thus, we cannot assume that means or variance in dose/response data from this "sample" are adequate for extrapolating to a risk assessment for a system with components other than those covered in the data base. Even more limiting, this data base by itself is insufficient for estimating the uncertainty of the extrapolation.

3.5 Recommendations for specific approaches

The logical, systematic framework of risk assessment offers a means for organizing the relevant factual information that is available which bears on predicting the outcome of some contemplated action (or inaction) with respect to environmental regulation, policy, and management. Risk assessment offers a methodology for making these predictions under conditions of uncertainty when available data are incomplete of dubious quality. More importantly, risk assessment allows the consequences of this uncertainty in the input data to be traced to the resulting uncertainty in the prediction. The sections to follow describe examples of the types of research activities that must be carried out to improve our information base; thereby improving our ability to perform more certain ecological risk assessments.

4.0 MAJOR RESEARCH AREAS FOR ADDRESSING THE INFORMATION NEEDS

4.1 Ecosystem classification and inventory

Inventory and classification measurements provide an information base for estimating the extent and location of specifically inventoried resources that are potentially at risk. These measurements also provide a means for extrapolating risk factors from small scale to larger scale systems that are potentially at risk. Effects on or hazards to resources supported by these ecological systems can also be evaluated. Any indication that environmental change is imminent or has taken place, must first be addressed by determining whether the change has actually taken place, or is currently taking place. The magnitude of the change and the extent of the landscape that is affected must be determined.

4.1.1 Ecosystem Components and Mapping

In order to extrapolate risk functions or effects from small to large scale, the landscape can be divided into natural units with coherent ecological processes, rather than political units. The structure of the ecosystem is currently reflected by measurements based on species diversity, importance indices, or selection ratios. Chemical compartmentalization is also measured to reflect the state of ecosystems using measurements of standing biomass or distribution and availability of nutrients. Research is needed to guide selection of proper divisions. Some examples of useful mapping projects are discussed below.

a. Eco-Region Concept

The eco-region concept used by EPA provides an example of a useful mapping project and also provides an excellent foundation for the studies described above. The concept is based on the observation that within a region the landscape is a mosaic of patches which form the components of pattern. The eco-region project shares this concept with landscape ecology, a relatively new ecological discipline, dedicated to improving our understanding of the development and dynamics of patterns in ecological phenomena. Research related to eco-regions and landscape ecology contributes to our capabilities in ecological classification and inventory.

b. LANSAT Mapping

Another ecological mapping project is represented by the on-going LANSAT project. This project produces maps that depict rainfall, temperature and geomorphology and are subjected to ground truth measurements to control accuracy. LANSAT maps may also show the state of vegetative sere development to reflect succession, and depict biomass measurements to reflect ecosystem state variables in terms of trophic level or vegetation types.

4.1.2 Inventory design

Several specific factors should be considered in designing the inventories used to establish landscape mapping units. These factors include determination of the error rate for classification of sites, determinations of within-class heterogeneity, and determination of uncertainty in extrapolation applications, including the assignment of site vegetation potential.

Data accuracy should be consistent with decision-making demands for variables that are related to identified issues. Furthermore, data accuracy in inventory design must be consistent with the design of future trends-monitoring, which will be compared to the initial inventory when making assessments.

4.1.3 Recommendations

In addition to the recommendation for approaches that can provide a firm foundation for extrapolation, studies documenting or describing the major life support services or values of various types of ecosystem should be conducted. The mapping and inventory projects designed to provide this foundation should include ecosystem status indicators that can be correlated with ecosystem function and value. Experimental studies are also needed to quantify ecosystem responses to major environmental and anthropogenic per-turbations and to test the utility of the parameters selected to measure ecosystem status in one or more systems.

4.2 <u>Ecosystem Monitoring</u>

Strategic monitoring elements are essential for determining changes or trends in ecological systems or environmental parameters influencing these systems. These strategic elements may be carried out as programs that involve repeated measurements of selected biological functions in conjunction with physical and chemical variables over time. Monitoring information is of critical importance to hypothesis formulation, hypothesis testing, ecological prediction and ecological risk analysis. Spectral analysis and other approaches involving data aggregation and pattern recognition techniques are proving useful. Such advances lead to a more complete understanding of ecological and environmental phenomena and cycles.

The long-term ecological research program of EPA should include provisions for both biological and chemical monitoring. Extended term monitoring is needed to track environmental pollutants such as ozone, SO_2, and NO_X and to reveal whether ecological systems are improving, deteriorating or remaining stable over time.

4.2.1 Historical deficiencies

As important as monitoring efforts are, they have historically been characterized by numerous limitations and deficiencies. The following are some of the most important:

a. Monitoring programs frequently lack clear definition and long-term justification.

b. Monitoring efforts commonly fail to recognize relevant temporal and spatial dimensions or scale.

c. Data sets from uncorrelated monitoring programs may not be compatible nor comparable. Mathematical characteristics, e.g. sensitivity, thresholds, correlation, indices, efficiency and uncertainty, all influence comparability of monitoring data. Protocol standardization, quality assurance and quality control measures must be coordinated in order to achieve compatibility.

d. Monitoring programs are inherently costly, and maintaining continuity of effort in mission, motivation, manpower and money is a sizable challenge. Feasibility, utility and scientific validity must be carefully evaluated along with expense and manpower requirements to ensure a successful strategy.

e. Monitoring efforts directed at documenting change in biological systems do not adequately distinguish

changes induced by natural forces from changes induced by anthropogenic forces.

f. Much of the environmental monitoring being undertaken by state and federal agencies appears to be designed solely or primarily to determine compliance with regulations.

g. Existing environmental monitoring programs, such as the air compliance monitoring program, are not well utilized in ecological effects programs.

h. There is no research effort to determine the most appropriate physical parameters, chemical species and biological measurements to monitor, although significant literature on this determination exists. Implementation of a research program dedicated to the identification of the most useful and cost-effective biological parameters to monitor is needed.

Long term ecological monitoring should be an integral part of the EPA's strategy for ecological research and risk assessment. There are a number of unknowns which make optimal design of such monitoring programs difficult. However, enough is known to initiate research programs which could be highly productive, generating observations about system status which will also serve as the basis for hypotheses and hypothesis testing.

4.2.2 Ecological status assessment

EPA is the most logical and appropriate organization to carry out a regular and systematic assessment of the status of the American environment. As a first step, the Subcommittee on Ecological Effects recommends that the Administrator establish a group specifically charged with and funded to carry out this important mission. The efforts of this group should include the following:

a. Assessment of existing and historical monitoring efforts

b. Storage, synthesis, and interpretations of available monitoring results

c. Identification of important gaps in the present acquisition of environmental monitoring data

d. Analysis of major environmental perturbations, both natural and experimental, that will assist in the design of future monitoring programs or in the interpretation of changes already observed

e. Development of a coordinated system for the collection and interpretation of ecological and environmental monitoring data within EPA.

Numerous monitoring programs have been in place for varying periods of time in a variety of Federal, state, regional and local agencies. Examples include the Status and Trends program and the Mussel Watch project in NOAA, the collection of commercial fisheries landing data by NMFS, the breeding bird count at the National Audubon Society, and the National Timber Inventories of the U.S. Forest Service. Numerous research programs are associated with existing monitoring projects; for example, the NSF Long-Term Ecological Research (LTER) sites forest watershed research programs (e.g. Coweeta, NC; Hubbard Brook, NH, Walker Branch, TN), estuarine sites (e.g Narragansett Bay, Chesapeake Bay) and the National Acid Precipitation Assessment Program efforts.

At present, there is no systematic and comprehensive collection, synthesis and interpretation of the results of these efforts. EPA ventured into such an effort in 1980 with publication of their "Environmental Outlook," but the effort was not sustained. While it may never be practical or possible to obtain and summarize all of these data, we presently lack even the general overview that was represented by the EPA document and formerly provided by the Council on Environmental Quality.

It is likely that an important finding from the first effort will be that there are major gaps in all of the existing monitoring programs. Based on a benchmark review, decisions can then be made about reducing redundancy in programs and embarking on new ones that may be carried out by EPA or other agencies.

4.2.3 Conclusions and recommendations

Current deficiencies in basic ecological research impede our abilities to design and implement a comprehensive ecological monitoring program. Nevertheless, the correct approach is to start a monitoring program based on our best available understanding, while at the same time initiating research programs which will yield knowledge to be incorporated into new and modified ecological monitoring designs. In other words, the Agency's ecological monitoring program must be designed to evolve for at least the first decade.

An ecological monitoring research program, taking advantage of existing ongoing monitoring programs, such as the National Surface Water Survey Phase IV, should be funded and implemented. The program's design should include quality assurance, and standardization of protocols, as appropriate. The statistical design selected should address EPA's research and predictive needs, as well as its regulatory requirements. In addition, EPA should conduct a regular and systematic assessment of the status of the American environment, applying this knowledge to determine the status of representative ecological systems, as well as reaching such conclusions on regional and local scales. Finally, long term environmental monitoring should be an integral part of the EPA's ecological research strategy.

4.3 Predicting ecosystem change

Many of the decisions that EPA must make involve predicting and preventing environmental damage, rather than cleaning up existing pollution. These range from discrete, relatively short-range decisions, such as establishment of water quality criteria for the protection of aquatic life, to long-range, even global decisions, such as limiting chlorofluorocarbon emissions in order to protect stratospheric ozone depletion. The Agency needs a predictive capability to anticipate and prevent emerging problems.

4.3.1 Limitations in predictive ability

For many issues of concern to EPA, the ability to predict ecological consequences is limited for several reasons. First, serious deficiencies exist in our understanding of the ecological effects of environmental perturbations. A CEQ Report on Long-Term Environmental Research and Development stated, "Our capacity to estimate ecological and environmental risks is not sufficient to ensure against either costly, and possibly irreversible, damage to essential biogeochemical cycles or preventable extinctions of endangered species and ecosystems" [2].

Second, many ecological problems are multi-faceted and interactive. Various stresses may be operating on a system simultaneously. These include both man-induced stress and extreme natural events, such as drought cycles, floods and other variations in climate. The interactive, cumulative and long-term influences of both natural and human influences on ecosystems means that their conditions often cannot be assessed in pollutant specific or project specific terms.

Third, experimental and observational approaches to develop predictive power need to be emphasized. EPA's research has focused on individual, short-range problems, rather than on the sustained and rigorous combination of approaches to ecological research that is necessary for the development of explanatory theory and fact to support predictive capabilities. The ability to predict environmental changes depends on the predictive power of the underlying science; and by strengthening this foundation, EPA can make significant advances in predictive capability while still carrying out its statutory responsibilities.

4.3.2 Considerations needed for ecosystem effects predictions

Developing the necessary next-generation of predictive methods and assessment techniques requires explicit incorporation of some important scientific considerations, including the effects of scale, both spatial and temporal, ecological interactions and resultant indirect effects, responses to multiple stresses, long-term effects and ecosystem variability. These considerations are discussed below.

a. Effects of scale, spatial and temporal

Ecological problems occur on various spatial scales: global (e.g., climate modification), regional (e.g., estuarine degradation), and local (e.g., site-specific fish kills. Scale is extremely important. For example, small scale elimination of species allows rapid replacement by immigration while large scale elimination does not. Extrapolation of results from one scale to another is difficult and must be done with caution.

In addition to spatial scale, consideration must also be given to temporal scale. Ecological systems may undergo natural change on time scales of hours to centuries. Ecosystems founded on primary production by plankton, such as open ocean systems, experience hourly diurnal fluctuations in dissolved oxygen. In contrast, forest ecosystems undergo community changes that occur over decades or centuries. Basic aspects of biological systems that are responsible for natural cycling and variability must be understood in order to clarify and predict the effects of perturbants.

b. Ecological interactions and indirect effects

Interacting communities of organisms have recovery capabilities and redundancies that individual organisms lack. Some populations may have extensive compensatory capabilities in one circumstance, but be driven to extinction in another. In ecosystems, actual effects of chemical exposure may be different from predictions that are based on individual organism responses. Exposure may be increased by bioconcentration processes or decreased by changes in bioavailability. Exposure to pollutants may cause a population to proliferate as a result of the elimination of its competitor or predator population, or as a result of complex interactions.

Thus a direct effect on one population (the predator/competitor) causes an indirect effect on another population. Such interactions points to the need for study of effects in complex ecosystems; that is, a study of the characteristics and behavior of the receiving environment, as opposed to the behavior of pollutants themselves.

c. Responses to multiple stresses

Episodic events, such as storms, droughts, and floods are naturally occurring events that cause variable responses in ecosystems. Pollutants also cause variations in response due to their chemical characteristics, source and route of exposure (e.g. point or non-point source). Physiologic stresses such as pH, UV or temperature also induce ecosystem responses. Traditionally, these stresses have been studied in isolation, to determine the mechanism of toxicity or physiological effect. However, ecosystems often experience multiple forms of stress, cumulating impacts over time, which cannot be elucidated by isolated or specific approaches. Understanding the effects of multiple stresses requires a more holistic approach in research design and data analysis.

d. Long-term effects

Long-term impacts may occur over time and over regions far removed from their source. Such responses may vary seasonally and from year-to-year, as well as by random a processes; therefore, they must be examined over long time frames to understand the significance of trends. Ecosystem level effects, such as chronic or cumulative degradation in river basins and estuaries, and impacts of intensive agricultural development may only be revealed by commitments to long-term investigation.

e. Ecosystem variability

Despite their similarities, not all ecosystems respond in a similar manner to perturbation. Many ecosystems are similar in overall structure, but differ considerably in species composition. Therefore, it is necessary to evaluate the effects of stress on several ecosystems. Ecologists need to investigate degrees of appropriateness for extrapolation among different ecological communities. Predictions are best if extrapolations are between similar systems and explicit knowledge of the differences between ecosystems will enhance extrapolation between ecosystems of different types.

4.3.3 Recommendations for advancing predictive capability

EPA's ecological research strategy must contain a minimum of three elements which, taken together, comprise a total approach to developing a predictive capability. Research projects themselves may deal with individual organisms, populations or subcomponents of the ecosystem; however, the strategic elements of the recommended research are focused on ecosystem-level questions. These three strategic elements are predictive studies, field experiments, and models.

The most fundamental element of the ecological research strategy involves predictive studies. Operational-level hypothesis testing with short-term experiments provide the advantages of maintaining control over experimental conditions, yet allowing study of system-level effects. Studies of processes such as transport, persistence, and bioaccumulation/bioconcentration yield basic data on effects of chemicals, mixtures or other perturbations at the ecosystem level. Microcosm research, as an example of such studies, is still in its early stages, yet offers great potential for advancing our understanding of system level effects while providing the basic inputs needed for predictive capability.

A second strategic element consists of longer-term experiments and observations of large-scale, natural ecosystems. In such systems, conditions are not controllable but instead reflect reality. Field studies serve to validate and expand on the conclusions and principles determined by short-term, simplistic experiments. EPA has some experience with this scope of research through whole-lake and watershed experiments designed to investigate delayed and direct responses to acid deposition. Opportunity for this type of research is provided via the Long-Term Ecological Research (LTER) Program of the National Science Foundation which provides the vehicle for collaborative investigation on ecosystem mechanisms and responses for a number of key ecosystems.

The last element of the recommended strategy is a modeling component. Fundamentally, models are used in ecosystem research in two ways.

a. Models provide a formal means for hypothesis development and testing along with a means for organizing and understanding the resultant observations and data.

b. Models can be used to extrapolate observations and the results of experiments to new or different situations.

This combination of capabilities make models powerful instruments for predicting environmental impacts. They may range from relatively simple, informal constructs that use prior experience to forecast change, to models that are complex, mathematically sophisticated, and capable of integrating and quantifying the facets that characterize environmental problems. They may be experiential, drawing on system measurements; empirical, extrapolating from statistical relationships; or qualitative process models, which incorporate some causal relationships.

A key part of mathematical model development is field verification and validation. Before such predictive tools can be applied to anticipating future ecosystem effects or ecological risk assessment, careful correlation of model predictions to actual field conditions must be made. The validation steps enable appropriate application of developed models to decision-making and priority setting problems that the Agency faces routinely. Ultimately, integration between ecological models, economic cost/benefit models, and resource management will be needed to facilitate policy or regulatory actions that are most effective in meeting societal needs.

5.0 INSTITUTIONAL CONSIDERATIONS

5.1 Organizational issues

As the Agency develops its long range ecological research program, it should formulate plans to transfer the knowledge gained to users outside the Agency. These plans should include mechanisms that allow EPA to take advantage of the data and knowledge that has been gathered outside of the Agency, incorporating these advances and eliminating duplication. States, localities, industries and other nations will benefit from and need to be apprised of research and monitoring findings in the Federal government. This is not only to assist them in their regulatory functions but also to allow them to evaluate the conclusions drawn relative to their own data and experience.

Recently an EPA task force explored the need for technology transfer and evaluated several options to facilitate such transfers. They formulated two basic conclusions:

> "EPA, working in partnership with the states, must take action to legitimize the importance and integral nature of technology transfer and training to its mission. As the Agency continued to evolve and mature, technology transfer and training must become core elements in supporting the Agency's operations and interactions with states and local government, industry and academic... Further, the task force believes that failure to incorporate such an emphasis throughout the Agency will undermine the effectiveness of the Agency's regulatory and enforcement efforts and related activities at the state and local levels" [3].

Significant changes will have to take place if the above goals are to be met, and the recommendations are to be effectively implemented.

An enhanced ecological research program would enable EPA to achieve the following goals [4].

a. Give greater consideration to ecological impacts in the Agency's ongoing regulatory programs -- e.g., biotechnology, Superfund, and natural resources damage assessment.

b. Play a broader leadership role as the nation's principal environmental agency, by assessing and responding to emerging large-scale or long-term environmental problems not directly covered by existing EPA regulatory activities -- e.g., global warming and decreased biodiversity.

c. Contribute to the advances in the state-of-the-science of applied ecology that will be necessary to anticipate, detect, and deal with future environmental problems, particularly those areas not being addresses by other Federal agencies.

5.1.1 Research committees

The current Research Committee vehicle for determining research priorities can address the first of the goals outlined above. However, it would be much less effective addressing the second and third goals. The immediate regulatory pressures confronting the EPA program offices will inevitably dictate short term research to supply information needs. Therefore, the Administrator of EPA should designate a given level of funding or percentage of EPA' research budget as available for long-term research, outside the purview of the Research Committees. At this stage, we are not in a position to recommend what the specific level or percentage should be.

At the same time, the relationship between Research Committee short-term research and independently directed long-term research must be sensitively handled by ORD leadership. First, there are important interrelationships and mutual contributions between the two types of effort. In that sense, the overall research program, although prioritized through two separate vehicles, should be managed as somewhat of a "seamless whole". Second, to assure continued Agency support, it will be important for ORD to constantly emphasize and demonstrate that the long-term effort is relevant to the Agency's larger goals. It is the special responsibility of research management to assure that the long-term research is not only of top scientific quality, but also focused and relevant to the Agency's overall mission.

5.1.2 Office of Monitoring

The Subcommittee on Ecological Effects recommends that the EPA establish an Office of Monitoring (or redirect the existing Office of Monitoring within ORD) to solve identified problems and implement the recommendations herein. This Office would:

a. Review existing monitoring programs and the information generated by such programs for relevance to EPA's objectives.

b. Identify important gaps in our present acquisition of environmental and ecological monitoring data.

c. Design and implement an EPA monitoring system, which considers quality assurance, standardization of protocols as appropriate, and relevant statistical design and analysis. Target this monitoring system specifically to addressing EPA's research, prediction, environmental and ecosystem assessment requirements.

5.1.3 Staffing

It will be necessary to make significant changes in staffing to implement the recommended program. Specifically, there is a need to add additional applied ecologists to EPA's staff at both Headquarters and at the laboratories to complement the current cadre of environmental scientists. There are a number of outstanding ecologists on EPA's staff; however, they are relatively few in number and unevenly distributed among the various research locations. It will be difficult to incorporate some of the recommended research concepts and rationale recommended in this report without expanding the number of researchers and broadening the disciplinary mix.

Hiring limitations of civil service personnel could make it difficult to implement this recommendation. However, there are a number of vehicles already utilized by EPA which can be given greater emphasis to achieve this goal. These include the Visiting Scientists and Engineers Program, Interagency Personnel Agreements (TPA), and fellowships through the American Association for the Advancement of Science (AAAS).

Particular emphasis should be placed on vehicles for rotating a small cadre of nationally known ecologists into EPA's Office of Environmental Processes and Effects Research (OEPER). These ecologists could be given significant assignments to incorporate a range of ecological approaches -- e.g. landscape ecology, adaptive environmental assessment -- into the Agency's research thinking. Recent organiza-tional changes in OEPER, specifically incorporation of the Agency's Acid Deposition research responsibilities, should facilitate this broadening of staff capability.

5.2 <u>Extramural vs. intramural research</u>

As in the case of staffing, focused use of extramural resources can broaden scientific participation in the research program. The current Acid Deposition research program demonstrates that ORD can bring such resources to bear in a focused way to address Agency needs.

We also endorse continued use of the Center of Excellence concept. While not specifically evaluating the programs of the two existing ecologically-oriented Centers (Cornell and University of Rhode Island), we would point out that these Centers have provided EPA with continuing access to necessary academic input. We would recommend continued management attention to the most effective use of those Centers and particularly to continuity and increased levels of funding.

EPA should play a stronger role in support and participation in such activities as the Man-in-the-Biosphere Program, and related programs within the appropriate professional societies. With relatively modest efforts, sometimes requiring only effective liaison or limited support of workshops or similar efforts, EPA can benefit from and influence the direction of these groups.

In addition, more explicit attention should be given to liaison and cooperation with related federal programs such as the National Science Foundation's LTER, the ecological research of the DOE National Laboratories, and relevant research of such agencies as the Forest Service and Fish and Wildlife Service. Major benefits can be achieved through such efforts.

5.3 Professional development

Implementing the foregoing strategy for ecological research will require a high level of professional ecological competence. Two forces are at work, which are creating a professional manpower problem within the Agency. One such force is the high attrition rate of an already dilute ecological talent pool. The age structure of the Agency's professional staff is inexorably moving upward. In excess of 40% of the professional staff will be eligible for full retirement benefits by 1990 and 75% will be eligible by 2000.

The second force is the need to ensure that there are enough students are in the academic pipeline to fill the spaces vacated by the retiring professionals, let alone to meet the manpower needs of an emerging program. Together the two forces, if left unchallenged, pose a problem that will rapidly reach crisis proportions. The obvious way to challenge these forces is to counter with the resources necessary to support programs for professional development. In the short run, use can be made of existing mechanisms (IPA, Cooperative Agreements, etc.) to bring talent into the Agency for relatively short (1-2 years) rotating terms. In the long run, however, a permanent, continuing supply of young talent can only be provided by supporting training programs designed to produce MS and Ph.D level scientists not only for the Agency, but for the Nation in general, since any surplus talent produced will find its way into state, municipal and industrial programs thus enhancing the Agency's technology transfer effectiveness. A training program similar to the one implemented by the Federal Water Quality Administraton (FWQA) and later dropped by EPA is strongly recommended.

5.4 Facilities and Equipment

In addition to its own unique laboratory and field facilities and equipment, ecological research needs strong analytical and computing support. The Agency's Environmental Research Laboratories were constructed twenty or more years ago during an era emphasizing single species toxicity and water quality testing. The equipment sufficient to accommodate that kind of activity has aged into marginal service ability if not become outmoded. Upgrading existing facilities and equipment is necessary in order to maintain the integrity of existing laboratory output. It is essential if quality ecological work is to be performed.

5.5 Resources

Substantial financial resources are required to fully implement the recommendations of the Subcommittee. This will pose significant difficulty under current budget constraints, yet several approaches are possible for initiating the proposed strategy. First, some of the recommended measures can be implemented with modest resource increments. These include strengthening and broadening ecological staffing, strengthening support for Research Centers, and increasing liaison and participation in relevant ecological activities. While these efforts will not substantially increase the level of new long-range research within EPA, they will greatly increase EPA's awareness of and access to relevant work and scientific input.

Second, the Agency could decide to redirect a portion of its research budget from short-term, Research Committee prioritized research to long-term efforts, rather than seeking entirely new resources. Such redirection could have an adverse impact on Program Office priorities and support for research, but it could be justified in relation to the Agency's broader goals.

Finally, It may be possible to redirect some of the Acid Deposition resources. This will allow the Agency to begin to address other closely related issues, such as global warming and stratopheric ozone deletion.

Even if all of these steps for initiating the proposed strategy are taken, successful implementation of, the ecological research strategy will still require a significant infusion of new funds and manpower. Anything less will serve only to compound the uncertainties we are trying to reduce.

References

1. U.S.EPA. 1987. Unfinished Business: A Comparative Assessment of Environmental Problems. Washington, D.C.

2. Council on Environmental Quality. 1985. Report on Long-Term Environmental Research and Development. Washington, D.C.

3. U.S.EPA. 1987. Report of the Administrator's Task Force on Technology Transfer and Training. Washington, D.C.

4. NAS/NRC. 1977. Research and Development in the Environmental Protection Agency. Washington, D.C.

APPENDIX I

APPENDIX I

STATUTES REQUIRING AN AUTHORIZING ECOLOGICAL RISK ASSESSMENT

STATUTE	SECTION	ACTIVITY FOR WHICH ERA IS AUTHORIZED
Clean Air Act (CAA)	154(c)	Studies by the National Science Foundation
	154(d)	Studies by the Secretary of Agriculture
	164(b)	Redesignation of areas as Class I, II, or III
	165(e)	Preconstruction requirements for major emitting facilities
Clean Water Act (CWA)	301(g)	Determinations on requests for water quality variances
	301(h)	Determinations on requests for modification of secondary treatment requirements for POTWS
	303(c)	Development of State water quality standards and designated uses for receiving water
	304(a)	Development of Federal water quality criteria and guidance
	305(b)	Development of State water inventories
	307(a)	Determinations regarding additions to, or revisions of, the list of priority pollutants
	311(b)	Designation of hazardous substances
	316(a)	Establishment of efficient limitations for thermal discharges
	320(b)	Development of estuary protection program

	403(c)	Development and provision of ocean discharge criteria
	404(c)	Determination of the effect of dredge and fill activites prior to authorization to discharge to surface waters
Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)	105(a)(8)(A)	Revision of the National Contingency Plan
	105(d)	Petition to conduct a preliminary assessment of the effects of the release or threatened release of hazardous substance
	105(g)	Addition of facilities to National Priorities List
	121(b) & (d)	Assessment of alternative remedial actions and degree of clean up required
	311(a)	Research on hazardous substance
Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)	3(c)(5)	Approval of registration of pesticide
	3(d)(1)(B)	Classification of pesticides for general use
	3(d)(1)(C)	Classification of pesticides for specific use
	5(d)	Experimental use permit studies
	20	Research and Monitoring
	25	Development of Regulations

Marine Protection, Research and Sanctuaries Act (MPRSA)		
	102(a)	Criteria for reviewing permits for ocean dumping
	102(c)	Designation of sites and times for dumping
	104(h)	Establishment of permitting criteria for low-level radioactive waste dumping
	104(i)	Establishment of permitting criteria for general radioactive waste dumping
	202(a)(2)	Research on ocean dumping
	303(b)	Designation of National Marine Sanctuaries
Safe Drinking Water Act (SDWA)		
	1427(d)	Development of criteria for identification of critical aquifer protection areas
Toxic Substances Control Act (TSCA)		
	4(a)	Testing to develop data with respect to environmental and human health effects of substances manufactured, distributed, processed, used or disposed of
	4(b)	Establishment of standards for the development of test data
	5(b)	Notification and submission of test data required for manufacture of a new chemical substance or the processing of a chemical substance for a new use
	5(h)	Evaluation of application for exemption from notification requirements for test marketing purposes

6(e)	Authorization of manufacture or use PCBs in a not totally enclosed manner
12(a)	Application for export of a substance being manufactured processed, or distributed

Summary of Statutory Authority Implicitly Authorizing an Ecological Risk Assessment

STATUTE	SECTION	ACTIVITY FOR WHICH ERA IS AUTHORIZED
Coastal Zone Management Act of 1972 (CZMA)	303	Declaration of policy
	305	Management Program Development Grant
Marine Mammal Protection Act of 1972 (MMPA)	3(a)	Moratorium and Exceptions
	103(a) & (b)	Promulgation of regulations on taking of marine mammals
	103(b)(3)	Consideration of the marine ecosystem and related environmental concerns
National Ocean Pollution Research and Development and Monitoring Planning Act of 1978 (NPERDA)	4(a)	Preparation of comprehensive 5 year plan for the overall Federa[l] effort regarding ocean pollutio[n] research, development and monitoring
	4(b)(1)(A)	Identification of the national needs and problems related to the specific effects of ocean pollution, including the effect[s] on the environmental value of the ocean and the coastal resources
	4(b)(1)(B)	Prioritize, with respect to value and cost, the national needs related ocean pollution which must be met
	6	Submit annual report to Congres[s] which estimates environmental

		impact of increased importing of foreign oil, evaluates the Federal government's ocean pollution research and monitorin capability, and summarizes the efforts undertaken to coordinate federal programs related to such research and monitoring
Resource Conservation and Recovery Act (RCRA)		
	1008(a)	Development and revision of guidelines for solid waste management
	3004(b)	Authorization for placement of hazardous waste
	3004(d) & (e)	Authorization for land disposal of hazardous waste
	3004(g)	Land disposal prohibitions of hazardous waste
	3004(m)	Development of waste treatment standards
	3005(j)	Study and Report to Congress on existing surface impoundments
	8001(a)	Research, demonstration, and training relating to hazardous waste management
	8002	Special waste studies
Wild and Scenic Rivers Act		
	Act in general	