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Research and Development
Fiscal Years 1997-1998
Research Accomplishments

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

The mission of the U.S. Environmental Protection Agency (EPA) is to protect human health and safeguard the natural environment — air, water, and land — upon which life depends. To meet this challenge, EPA has developed a strategy that combines strengthening the current system of environmental regulations and designing approaches to provide better environmental protection at less cost. The success of this strategy depends in large part on making credible environmental decisions based on sound science. Working in partnership with EPA's program and regional offices, EPA's Office of Research and Development (ORD) is dedicated to developing the scientific knowledge and innovative technological solutions needed to ensure the success of this strategy to achieve EPA's mission.

As EPA's Assistant Administrator for Research and Development, I am proud of the expertise and dedication ORD's scientists, engineers, and other personnel bring to addressing the environmental challenges of today and tomorrow. ORD's researchers are expanding our nation's scientific knowledge about the environment, developing guidance for assessing both human health and ecological risks, devising new technologies and risk management approaches to both prevent and mitigate pollution, and providing technical assistance to those working to protect our environment. All of our work is guided by sound scientific principles, including independent peer review, to ensure that our contributions are consistently of the highest quality.

This report communicates ORD's most significant research accomplishments during 1997 and 1998 in support of EPA's mission. A few example highlights include:

- Development of improved methods for detecting drinking water contaminants to reduce outbreaks of illness.
- Creation of computer-based models of long-range transport of air pollution that can be used by states in designing pollution control programs.
- Demonstration of strategies to reduce children's exposure to lead in the home, a risk factor for impaired nervous system development.
- Evaluation of the potential of chemicals to interfere with the endocrine system of humans and wildlife.
- Development of advanced methods for monitoring the condition of the environment, using data sources such as satellite imagery and ground-based ecological measurements.

I hope you will take the time to read about the significant ways ORD's research contributes to our understanding of environmental issues, especially in the areas of *particulate matter, drinking water, risk assessment, ecological assessment, and endocrine disrupting chemicals.* We in ORD remain committed to bringing our creativity and technical expertise to meeting the highest priority science needs in support of EPA's mission.

Norine E. Noonan

Norine E. Noonan, Ph.D.
Assistant Administrator
for Research and Development

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Introduction

As we get up each morning and get ready for another day, we often take for granted that the water from the faucet we use to make our coffee is drinkable, the food we feed our children is safe, and the air we breathe is healthful. Not until we need to take unusual steps, such as boiling our water to eliminate microbial contamination or reducing physical activity on ozone action days, do we realize how fragile our environment can be and how important it is to protect it. The mission of the U.S. Environmental Protection Agency (EPA) is to protect human health and to safeguard the natural environment – air, water, and land – upon which life depends. Although EPA has made substantial progress in both cleaning up and protecting these natural resources, many challenges remain, and new human health and environmental problems continually confront the Agency.

Responding to these challenges requires research to understand these problems and to develop technologies to solve them. The Office of Research and Development (ORD) is the primary arm of EPA responsible for carrying out this work. ORD supports EPA's mission by conducting state-of-the-art research in all environmental media (air, water, and land) to address unanswered scientific questions. As part of its research efforts, ORD develops innovative methods and approaches for solving problems that range from broad scientific issues such as global climate change, to specific problems such as removing microbes from drinking water systems. To make the most efficient use of resources and research dollars, ORD relies on extensive collaboration among ORD Laboratories and Centers, EPA partners in the program and regional offices, and the external scientific community. In addition, ORD has made independent peer review an integral part of its programs to ensure ORD's research is of the highest quality.

This Research Accomplishments Report highlights selected accomplishments completed by ORD during Fiscal Years 1997 and 1998. We hope this report will help you better understand the environmental problems all of us face, and the role of EPA's research in helping to solve them. The report features significant accomplishments that have advanced our scientific and technical knowledge and capabilities, as well as ongoing activities that will generate future accomplishments. Accomplishments in five broad research areas are described in depth in the report (main topics), and accomplishments in nine other research areas representing either emerging environmental issues or issues narrower in scope are described more briefly (shorter topics). In each topic area, the major scientific problems are defined, the scope of ORD's research program to address these problems is outlined, selected accomplishments are highlighted, and the direction of future research is described. The topics are:

Main Topic Areas:

1. Health Effects of Airborne Particulate Matter
2. Drinking Water: Microbial Pathogens and Disinfection By-Products
3. Advances in Risk Assessment
4. Mid-Atlantic Integrated Assessment (MAIA)
5. Endocrine Disruptors

Shorter Topic Areas:

6. Environmental Risks to Children
7. Harmful Algal Blooms
8. Pollution Prevention
9. U.S.–Mexico Border Environmental Health
10. Monitored Natural Attenuation
11. Global Climate Change
12. Arsenic in Drinking Water
13. Economic and Decision-Making Research
14. Ecological Indicators

The research accomplishments presented in this report represent only a snapshot of ORD's dynamic, evolving research portfolio. Nonetheless, these accomplishments describe some of the key research that supports important EPA decisions, and the report presents ORD research in a comprehensive, integrated format that is an alternative to the more focused reporting of research results in the scientific literature and other publications.

Credible Environmental Research

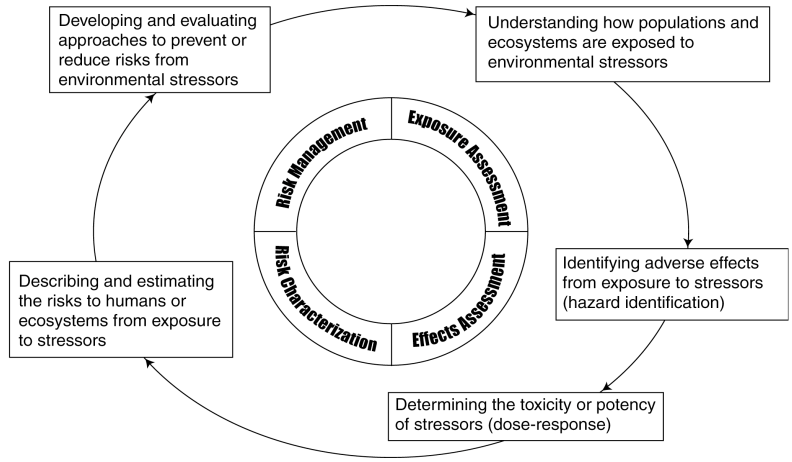


Figure 1. The risk assessment-risk management framework used by ORD to organize its research and development activities.

For any research organization to have credibility within the scientific community, its research must be able to withstand the rigors of scientific scrutiny. ORD has made the peer review process an integral part of its research program to ensure that its research is based on sound methodologies and generates credible data. Peer review is an independent evaluation of a work product by experts who have not participated in developing the work product. Peer review can be internal (evaluation by experts within EPA), or external (evaluation by independent experts outside of EPA, such as EPA's Science Advisory Board). ORD recognizes the importance of its research to both the Agency (for use in regulatory decisions) and the scientific community (for application to specific environmental problems), and strives to conduct the best science possible.

The Risk Paradigm

To understand ORD's research program, it helps to be familiar with the "risk paradigm," an important Agency organizing principle. The risk paradigm consists of two interrelated phases, risk assessment and risk management. Risk assessment is the process used to evaluate the degree and probability of harm to human health and the environment from such stressors as pollution or habitat loss. The risk assessment process, as proposed by the National Academy of Sciences (NAS) in 1983, consists of:

- Exposure Assessment - describing the populations or ecosystems exposed to stressors and the magnitude, duration, and spatial extent of exposure
- Hazard Identification - identifying adverse effects (e.g., short-term illness, cancer) that may occur from exposure to environmental stressors
- Dose-Response Assessment - determining the toxicity or potency of stressors
- Risk Characterization - using the data collected in the first three steps to estimate and describe the effects of human or ecological exposure to stressors

Risk management entails determining whether and how risks should be managed or reduced. It is based on the results of the risk assessment as well as other factors (e.g., public health, social, and economic factors). Risk management options include pollution prevention or control technologies to reduce or eliminate the pollutant or other stressor on the environment. The environmental or public health impacts resulting from risk management decisions must then be monitored so that any necessary adjustments can be made. A simple diagram of this cycle of risk assessment and risk management is shown in Figure 1 (with the steps of hazard identification and dose-response assessment combined into a category entitled Effects Assessment).

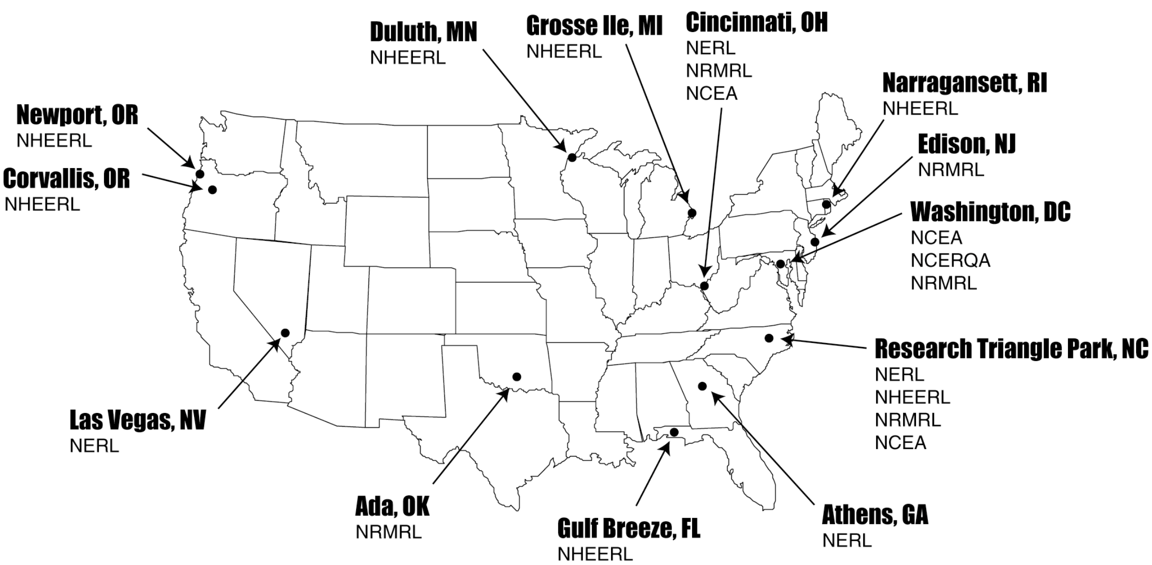
ORD has aligned its organizational structure to comport with this risk paradigm and has made the principles central to its strategy for determining priorities for environmental research. Several topics in the report are presented in terms of the risk paradigm, with accomplishments linked to discrete components of the paradigm. For other topics the risk paradigm was not used, either because the accomplishments could not be cleanly divided among the different risk steps or because most of the accomplishments fell within a single step of the paradigm.

ORD Laboratories and Centers

ORD comprises three National Laboratories and two National Centers. Most of the National Laboratories and Centers have multiple research facilities (Figure 2). The brief descriptions of the ORD Laboratories and Centers listed below include which aspect of the risk paradigm they support (italics).

- **National Health and Environmental Effects Research Laboratory (NHEERL)** (www.epa.gov/nheerl/) conducts research on the effects of contaminants and environmental stressors on human health and the environment. *Hazard identification and dose-response assessment*
- **National Exposure Research Laboratory (NERL)** (www.epa.gov/nerl/) conducts research to improve the scientific bases for human and ecosystem exposure assessment. *Exposure assessment*
- **National Center for Environmental Assessment (NCEA)** (www.epa.gov/ncea/) conducts research in risk assessment methods, and serves as a national resource for human health and ecological risk assessment by conducting assessments and developing new methods and tools for risk management. *Risk characterization*
- **National Risk Management Research Laboratory (NRMRL)** (www.epa.gov/ORD/NRMRL/) conducts research and technology transfer to prevent, mitigate, and control pollution. *Risk management*
- **National Center for Environmental Research and Quality Assurance (NCERQA)** (www.epa.gov/ncerqa/) manages an extramural research program (grants, fellowships, and national centers of excellence) known as Science to Achieve Results (**STAR**) to complement ORD's internal research program and expand EPA's science and technology base. NCERQA also develops EPA-wide quality assurance policies and manages EPA's peer review process. *All phases of risk assessment and risk management*

With this approach and organizational structure, ORD can assure that science resources are directed to the most pressing environmental problems posing the greatest risks to people and the environment. We will continue to bring our creativity and technical expertise to meet the environmental science needs of today while positioning ourselves to identify and aid in resolving the environmental problems of tomorrow.



NCEA	National Center for Environmental Assessment
NCERQA	National Center for Environmental Research and Quality Assurance
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Research Laboratory
NRMRL	National Risk Management Research Laboratory

Figure 2. ORD Locations.

1. Health Effects of Airborne Particulate Matter

In December 1952, a choking black fog enveloped London, darkening the city during the daytime. Unusual weather conditions trapped a mass of stagnant air that filled with the smoke from tons of burning coal. By the time the air cleared, an estimated four thousand residents of the metropolitan London area had died, with the elderly and people with heart and respiratory ailments especially affected. Studies that have looked back on the event have concluded that tiny, inhalable particles found in the smoke – also known as particulate matter (PM) (Figure 1-1) – played a crucial role in the deaths. Similar events, though less catastrophic, occurred in the United States and other parts of Europe during the middle decades of the century.

In the nearly 50 years since the London episode, air quality has improved dramatically in the U.S. and Western Europe. One of the major reasons for the improvement seen in the United States is the Clean Air Act, which had its beginnings in the enactment of this nation's first federal air pollution law, the Air Pollution Control Act of 1955. Since then, the Clean Air Act has been amended many times, leading to strengthened regulatory programs to reduce particle emissions from power plants, motor vehicles, and other combustion sources. Clean Air Act requirements have also contributed to a vastly improved scientific ability to detect and understand health effects from particles and other air pollutants.

A key section of the Clean Air Act Amendments requires EPA to review the risks to public health and welfare from PM (and other major pollutants) every five years to determine whether to revise air quality requirements known as the National Ambient Air Quality Standards (NAAQS). This continual cycle of NAAQS review assures that the Agency considers the most recent scientific research as it decides whether to revise a current standard. To implement this provision, ORD is responsible for periodically preparing comprehensive Air Quality Criteria Documents that present the analysis, review, and assessment of the latest available scientific information on major air pollutants. These documents serve as written consultations on the current state of the science for use in environmental decision-making by risk managers in EPA's Office of Air and Radiation.

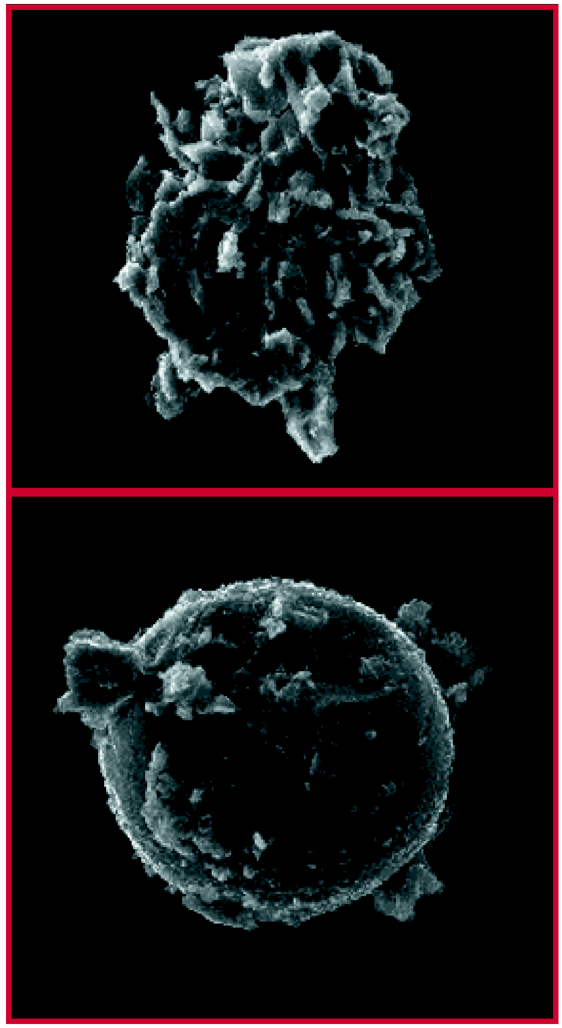


Figure 1-1. **Examples of fine particles.** Airborne particles appear in a variety of sizes and shapes and differ in their composition. They also can grow in size in the atmosphere as additional materials condense on or collide with the particles. These particles were captured in samples of outdoor air from Washington, DC.

EPA's most recent review of the PM NAAQS was supported by ORD's 1996 document entitled Air Quality Criteria for Particulate Matter (EPA 600/P-95/001aF). This document explained that particles can be comprised of many chemicals, such as organic material, acids, metals, and oxides. It also noted that PM consists of particles in a range of sizes, commonly differentiated by fine PM or $PM_{2.5}$

(particles less than 2.5 micrometers in diameter), and coarse PM (between 2.5 and 10 micrometers in diameter). The report concluded that fine particles were more consistently associated with health effects than coarse particles. Based on the ORD report and other findings, EPA published a Staff Paper estimating that current PM levels may cause tens of thousands of premature deaths each year as well as hundreds of thousands of cases of hospital admissions, aggravation of asthma, and other health effects.

After considering ORD's review and extensive public comments, EPA revised the NAAQS for PM in 1997. The most significant change was the addition of a new standard to protect the public from $PM_{2.5}$, which can penetrate deeply into the lungs. The prior standards were based on PM_{10}, which encompassed all particles less than 10 micrometers in diameter. (As of 1999, the new standards were the subject of a lawsuit that may result in changes to the PM NAAQS.)

Given the potential magnitude of health risks, the need for better understanding of PM, and Clean Air Act review requirements, ORD is carrying out a major PM research program. This research will be essential for EPA's reviews of the PM NAAQS scheduled for 2002 and 2007. Ultimately, the goal of EPA's research program is to provide the scientific and technological basis for developing and implementing the Clean Air Act standards so that all Americans enjoy clean, safe air.

ORD's Research Program to Answer Outstanding Scientific Questions

Although ORD has made considerable progress in understanding the health impacts of PM, substantial uncertainty still exists. With each review of the NAAQS, research fills gaps in our knowledge and refines unanswered questions (or raises new ones). Finding answers to outstanding questions is important because of the implications for protecting the public. If certain emission sources are found to be most responsible for health effects, for example, efforts to reduce emissions can target these sources. As described in the Introduction, ORD uses the risk assessment/risk management framework to organize its research approach in solving scientific and technological problems. This framework is visually portrayed in the inner ring in

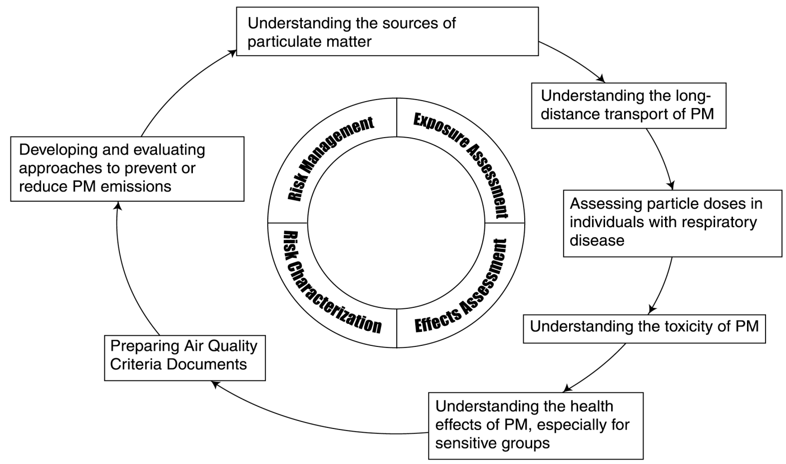


Figure 1-2. Some of the major research and assessment activities conducted by ORD in examining the health effects of airborne particulate matter.

Figure 1-2, with ORD's major PM research and assessment activities depicted by the outer ring. ORD has focused on the following types of questions in these research areas over the past several years:

- **Exposure:** Who is exposed to PM? What are the characteristics of the particles people are exposed to? How much PM are they exposed to?
- **Health effects:** What are the health effects of exposure to PM? Who is affected by exposure to PM? What levels cause adverse effects? What are the characteristics of particles responsible for adverse health effects?
- **Risk characterization:** What are the overall risks to the public given exposure and potential health effects? What uncertainties remain in the research data?
- **Risk management:** What are the major sources of PM in the atmosphere? What are the most cost-effective ways to reduce or prevent the risks associated with exposure to PM?

The scientific products of ORD's PM research, as in the rest of EPA's research program, are closely scrutinized through independent peer review to ensure they are of high quality, credible, and advance the state-of-the-science for PM. In addition, ORD strengthens its PM program and reduces duplicative efforts through partnering/collaborating with many of the public and private organizations that are also conducting PM research. A few of ORD's partners include the National Institute for Environmental Health Sciences, Department of Energy, NOAA, Health Effects Institute, NARSTO (a public/private partnership focused on atmospheric science), and the World Health Organization. The goal of ORD's PM research program is to reduce the uncertainties in understanding the risks from PM to humans, which directly supports each evaluation of the PM NAAQS, and to provide a scientific and technical basis for implementing effective control measures.

Recent Accomplishments

Understanding the Health Effects of Particulate Matter, Especially for Sensitive Groups

How do the airborne particles we breathe lead to hospitalization and even death? ORD is seeking the answer to this question through studies involving people, laboratory animals, and cell cultures. ORD's study with the University of North Carolina of a group of elderly persons in Baltimore, Maryland over the past two years has yielded insights into the changes in heart and lung functioning that may indicate more serious illness following exposure to PM.

In the first year of the study, ORD researchers chose 26 volunteers from a retirement community and studied them for three weeks. A retirement community was chosen for study because the elderly have been found to be more susceptible to PM effects. PM levels outdoors and indoors were monitored at the same time that various physiological measures, such as lung function and heart rate, were measured for each participant (Figure 1-3).

Figure 1-3. A volunteer in the Baltimore study exhales into a peak expiratory flow meter, which measures lung function. These results were correlated with indoor and outdoor PM levels to evaluate lung effects from PM exposure.

A surprising finding was that as $PM_{2.5}$ levels rose, people with pre-existing heart problems experienced lower heart rate variability. Lower heart rate variability is a well-established factor in sudden death from heart attack and, consequently, may represent an important link in the sequence from breathing particles to adverse effects. In 1998, ORD expanded the study to include 60 volunteers and more in-depth air pollution monitoring over four weeks, and results are now being analyzed.

ORD has also performed laboratory studies that complement the Baltimore work. In one set of studies, ORD scientists found that fine particles (PM_1) were deposited at a rate 50% higher or more in the lungs of people with pre-existing respiratory disease than those with healthy lungs. ORD researchers also exposed laboratory rats and mice with respiratory diseases (similar to human cardiopulmonary disease and asthma) to PM. These experiments identified abnormalities and inflammatory changes in lungs and cardiac changes that are in agreement with the adverse effects observed in people. An example of adverse effects in a rat lung from PM is shown in Figure 1-4. From these findings, a picture of how particles may be causing effects is beginning to emerge. Individuals with pre-existing respiratory disease seem to face greater risks not only because of their underlying disease but also because more particles penetrate into their lungs. Once deposited on the surfaces of the lungs, particles may cause damage that further impairs the functioning of the heart and lungs. If sufficiently severe, the damage can induce serious and even fatal illness. But what aspects of the particles render them toxic?

Understanding the Toxicity of Particulate Matter

The biological, chemical and physical characteristics of PM, and their relationship to mechanisms underlying the toxic effects of PM are not well understood. Major hypotheses state that lung inflammation and cardiopulmonary stress produced by PM are related to particle size and to the chemical nature of PM, such as acidity, organic chemicals on particle surfaces, or metal content. ORD research, using both human and animal studies, is providing critical insight into how these factors may cause adverse effects in humans. The

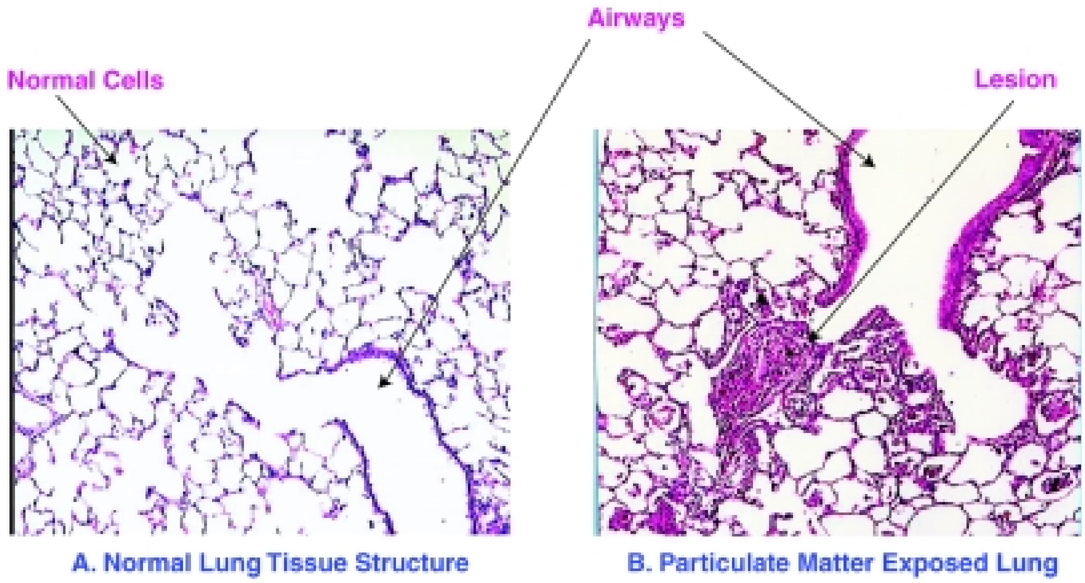


Figure 1-4. Comparison of the lung of a rat exposed to saline solution (A), with no effects seen, to the lung of a rat exposed to ambient air particulate matter (B), where a lesion has developed.

supposition that metals co-existing with particles is one important factor in the events leading to PM health effects has captured particular attention among several scientific investigators at EPA (Figure 1-5), and the following studies were designed to test this theory.

ORD toxicology studies have examined a source of PM with high metal content, residual oil fly ash, emitted by power plants. A study published in 1997 reported that different metals each can cause injury to rat lungs, and in combination the metals appear to account for much of the toxicity of the particles (Figure 1-6).

ORD studies on residual oil fly ash and other emissions set the stage for investigations into the role of metals in PM toxicity in a specific geographic area, the Utah Valley. A labor strike that temporarily closed a major polluting industry in the Utah Valley provided a unique opportunity to compare the effects of exposure to PM in air when the industry was in operation versus when it was not. Epidemiology studies had reported that particle-related mortality declined during the year workers were on strike. ORD researchers studied samples of ambient PM collected over a three-year period in the Utah Valley before, during, and after the strike to elucidate its toxic properties. In addition, tests were conducted in cultured lung cells, in laboratory animals, and in human volunteers. Tests with cultured lung cells showed that these cells initiated a chain of events that would trigger lung inflammation when exposed to air collected during industry operations. Inflammation can indicate cellular damage. ORD toxicologists discovered that metals associated with the PM were strongly correlated with the cell response that triggered inflammation.

Ambient PM collected from the same location (Utah Valley) also was instilled into the lungs of animals and human volunteers to understand how metals injure lungs within an organism. The research showed that metals associated with PM, such as iron, copper, and zinc, caused lung damage. Although some metals were more toxic than others, the toxicity appeared to be related to the type of lung cell exposed in the experiments. ORD also discovered that even though different metals can cause similar toxic effects in lungs, they may do so in different ways.

Other research examining the metal hypothesis includes ORD's groundbreaking efforts with free radicals (highly reactive atoms or groups of atoms with an unpaired electron). ORD scientists were the first to show that free radicals occurred in the lungs of rats exposed to metal-bearing particles, and that metals capable of producing free radicals also caused lung inflammation in humans. This research suggests that toxicity appears to be related, in part, to the formation of free radicals in the lung caused by metals.

University researchers funded under EPA's STAR Program have also examined how PM causes toxicity. Investigators found brief exposures of one hour to residual oil fly ash evoked stress response from human airway cells sufficient to release interleukin-8, a factor associated with airway

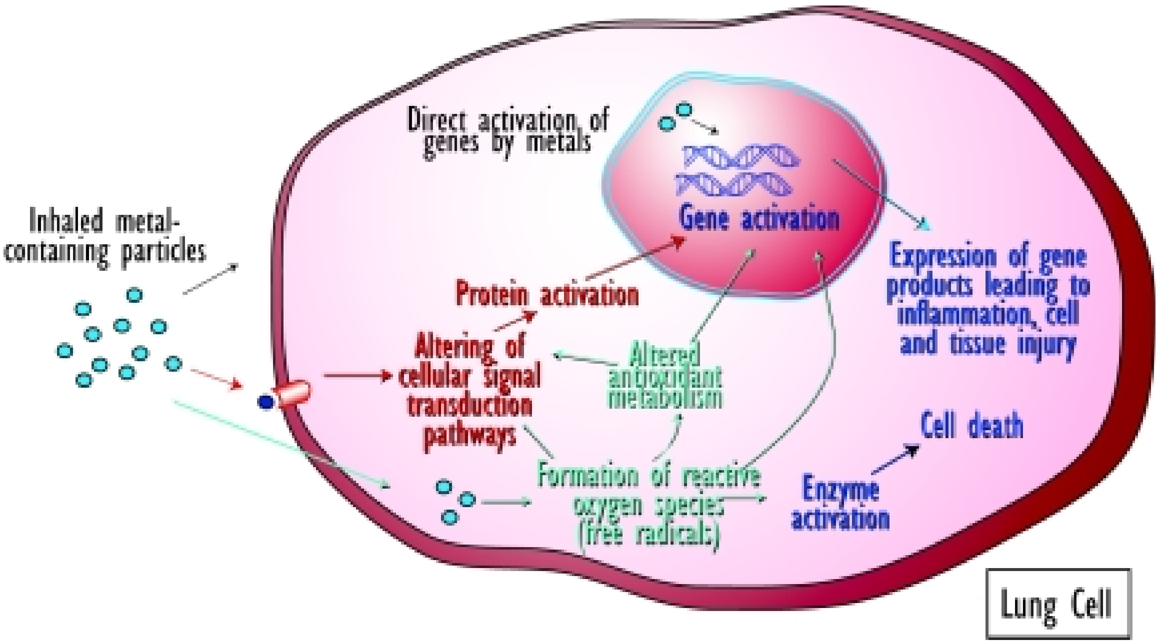
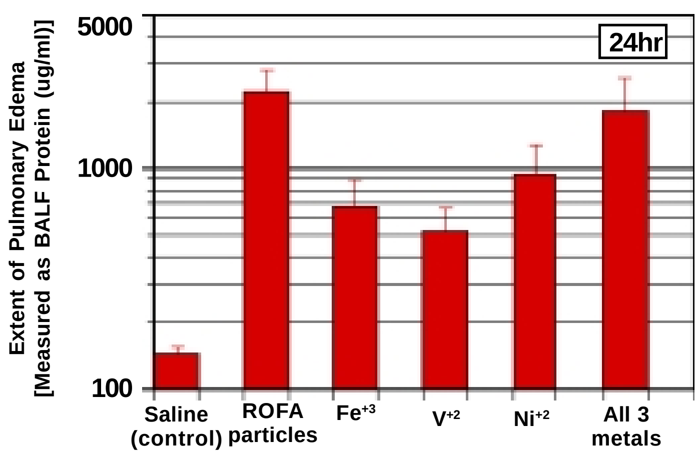


Figure 1-5. **The metals hypothesis of particle toxicity.** ORD researchers are investigating the role that metals contained in particulate matter may play in toxicity. It has been proposed that metals in particles can act on cells in several different ways that result in toxicity, including by directly interacting with genes (through metal response elements), by acting through cellular signaling pathways, and by generating highly reactive oxygen species.

inflammation. Other STAR researchers examining PM toxicity in the lungs of rats and monkeys confirmed that cell injury may be due to a cascade of events in the lung following short-term exposures to PM. Cell injury was independent of ozone exposure and occurred in different parts of the lung.

Understanding the Sources of Particulate Matter

We now have a better understanding of the adverse health effects of PM, and potential causes of toxicity, but what are the physical, chemical and toxicological characteristics of PM emitted by various sources? To answer this question for sources that burn heavy fuel oil, ORD engineers and health scientists have evaluated PM from different fuels (of two grades and three sulfur contents) burned in EPA research boilers that are representative of small industrial, commercial and institutional applications. The composition of the PM varied with particle size, with $PM_{2.5}$ composed of significantly higher levels of metals and sulfates than the larger particles (see Figure 1-7). Animal toxicological testing revealed greater pulmonary damage by the fine particles.



Modified from K.L. Dreher, et al., J. Toxicol. Environ. Hlth., 1997. Dose: 2.5 mg/rat

Figure 1-6. **Role of metals in particle-induced lung injury.** Lung injury in rats from a saline solution control is compared to injury from a suspension of residual oil fly ash (ROFA) particles and to solutions containing iron (Fe^{+3}), vanadium (V^{+2}) and nickel (Ni^{+2}) at the same concentration as found in ROFA. Each metal causes toxicity, and in combination the metals appear to account for much of the toxicity of the ROFA particles.

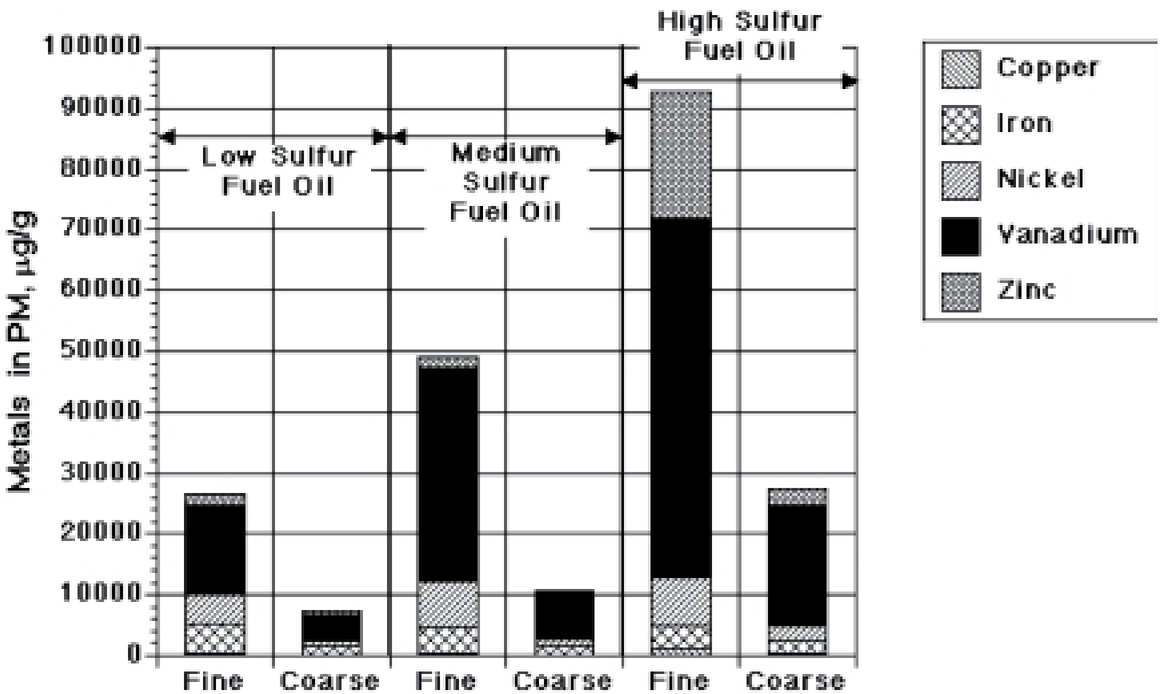


Figure 1-7. The metals content of PM from combustion of heavy fuel oil is highly dependent on particle size, with fine particles ($PM_{2.5}$) containing higher concentrations than larger particles. Data from C.A. Miller et al., Combustion Science and Technology, 1998.

These tests showed that the mechanisms by which fine particles are formed are significantly different than those governing the formation of larger particles. These different mechanisms lead to substantial differences in chemical composition, especially the higher content of metals and sulfates observed in the fine PM. The mechanisms apply to combustion systems in general, including coal and other fuels. This work has therefore been important in identifying toxic constituents of combustion PM and in setting research priorities for control of combustion emissions.

Additional studies have characterized particle emissions from large diesel trucks as they are traveling along the highway. ORD researchers equipped a tractor-trailer rig for real-time emission monitoring and made first-of-a-kind measurements of fine PM (less than 1 micrometer in diameter) emissions under highway conditions. Simultaneous measurements were made from the exhaust pipe and in the plume left by the truck. These data will enable air quality regulators to make better estimates of the impact of large diesel trucks on ambient air quality.

Another significant source of fine PM in certain parts of the country is residential wood combustion. ORD researchers have made field and laboratory measurements that have shown that emissions from wood stoves are strongly affected by moisture content of the wood and how a homeowner operates the stove, as well as stove type and condition. Even stoves that had been certified as clean burning when purchased did not maintain their high level of emission control for very long. Most had significant loss of control effectiveness after a few years of use. These data will influence control strategies to meet PM standards in areas with high usage of wood stoves.

Understanding the Long-Distance Transport of Particulate Matter

An air sample from a typical American city can contain particles from an astonishing variety of sources, ranging from nearby buses and cars, to power plants or forest fires hundreds of kilometers away, to even the Sahara Desert on the other side of the globe. Scientists look for unique "signatures" or characteristics of the particles that may reveal their source and use computer models to show how particles move in air currents to decipher where airborne particles come from and predict where they will go.

In 1998, ORD reached a major milestone in its efforts to understand the movement of particles and other air pollutants when it publicly released the *Models-3 Community Multi-Scale Air Quality* model. This computer model, available free of

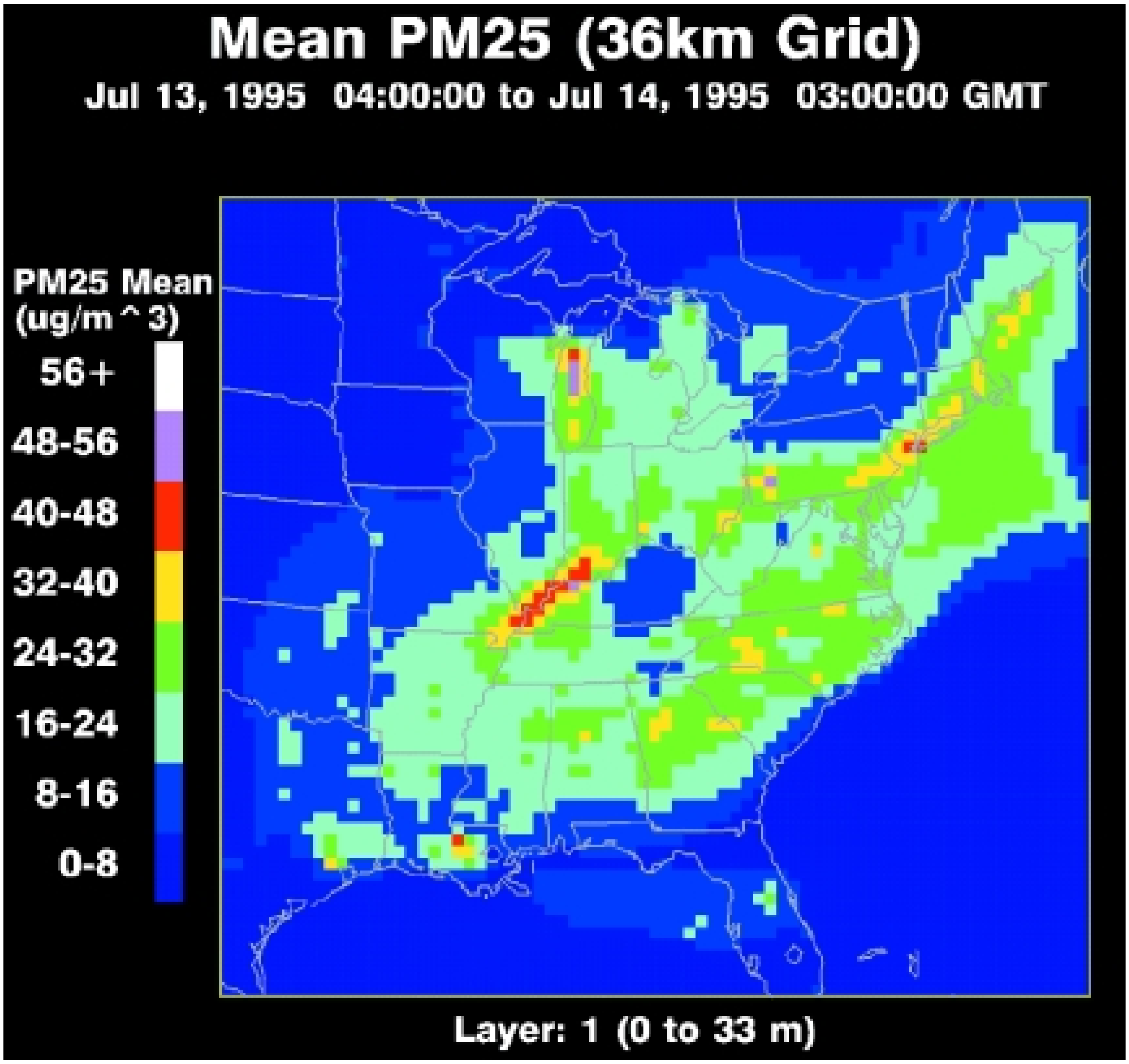


Figure 1-8. Graphic of $PM_{2.5}$ mass (24-hour average) across the eastern U.S. generated by Models-3, an ORD air quality computer model.

charge on the Internet (www.epa.gov/asmdnerl/models3/), is the first to simulate the concentrations of multiple air pollutants simultaneously and show their movement across entire regions or subcontinents. An example of the type of data that can be generated by Models-3 for PM is shown in Figure 1-8. By manipulating simulated emissions of particles and particle precursors, users of the model can gain valuable insights into the likely effects of various strategies to control PM, ozone, and other air pollutants. As a result, EPA expects that Models-3 will be used extensively by environmental managers in state and local governments and by scientists who develop air quality modeling systems. ORD plans additional refinements of Models-3 as more extensive $PM_{2.5}$ monitoring data become available.

Several studies funded under the STAR Program also have focused on understanding and modeling particle transport. STAR investigators have developed a new chemical model that describes how particles are formed in the atmosphere. It incorporates up to 335 chemical reactions simulating the formation, growth, and removal of particles in the atmosphere. This will improve the ability of air quality models to accurately assess the contributions of both emissions related to human activity and biogenic (naturally formed) emissions to ambient PM levels. Other studies have included a pilot field study that characterized the formation, fate and transport of fine particles and ozone using vertical profile measurements. This effort demonstrated the importance of transported pollutants in the initiation of PM and ozone events in Philadelphia. Finally, researchers have documented a sharp decrease in sulfate particle concentrations in the northern United States that may be related to the reduction of sulfur dioxide (SO_2) emissions in the Midwest. The researchers reached their conclusions by obtaining and analyzing measurements of SO_2 and sulfate from 1979 through 1996 in New York State.

Where Do We Go From Here?

The particulate matter models and studies described in this report have helped answer important questions about the sources of PM, how people are exposed, and the health effects that PM can cause. ORD is using these findings, along with the discoveries of other research organizations, to refine the direction of its comprehensive research program for particulate matter. The program is designed to reflect the near and long-term research priorities presented to EPA by the Committee on Research Priorities for Particulate Matter of the National Research Council. As ORD carries out this program, it continues to use the risk assessment/risk management framework depicted in Figure 1-2 to organize and integrate its research.

Within the general category of exposure assessment, for example, ORD is conducting atmospheric sciences research under the aegis of NARSTO, a consortium of public and private research organizations of which EPA is a member. NARSTO was originally created to coordinate North American atmospheric research on tropospheric ozone in support of air quality management. It has recently expanded its mission to encompass PM research following findings by ORD and others that have improved understanding of the linkages between ozone and particulate matter in the atmosphere. ORD scientists are conducting PM research in areas such as monitoring, emissions, atmospheric chemistry and processes, and modeling under NARSTO.

ORD is also conducting studies that will contribute to exposure assessment and effects assessment in such areas as particle dosimetry, particle toxicity, and the role of PM and associated air pollutants in adverse health effects. For example, ORD is building on its research on the effects of PM in susceptible individuals by carrying out “panel studies” that follow small groups of individuals over time through intensive personal exposure monitoring and activity diaries. ORD is also extending the initial findings of the study of elderly Baltimore residents by completing more thorough analyses and conducting a similar study in Fresno, California. Health effects assessment is also being advanced through targeted toxicology studies in both laboratory animals and clinical studies by both EPA laboratories and through the STAR program.

In the area of risk characterization, ORD will review and summarize the exposure and health effects work by ORD and others in the next Air Quality Criteria Documents for PM, currently scheduled for 2000 and 2005. These documents will present the state-of-the science for particulate matter and will be critical in EPA’s review of the national standards for PM levels in the ambient air.

Finally, ORD is conducting risk management research to evaluate the cost and effectiveness of options for reducing emissions of both particles and gaseous precursors that develop into particles in the atmosphere. Examples include working with electrical utilities to design and test electrostatic filters and fluid bed scrubbers to control emissions at power plants. This research will help EPA, states, and industry develop cost-effective strategies to reduce exposure to particulate matter, thereby protecting public health.

2. Drinking Water: Microbial Pathogens and Disinfection By-Products

In 1993, contaminated drinking water in Milwaukee, Wisconsin, brought about an outbreak of cryptosporidiosis (caused by the microorganism *Cryptosporidium parvum)* that resulted in approximately 400,000 cases of acute gastroenteritis and about 100 deaths. This outbreak represents the largest documented occurrence of disease associated with contamination of a water supply in the United States. According to EPA and the Centers for Disease Control and Prevention, during 1991-1996 more than 40 outbreaks of waterborne disease occurred due to contamination by a variety of bacteria (e.g., *E. coli*), viruses (e.g., Norwalk virus), and parasites (e.g., *Cryptosporidium* and *Giardia lamblia*) (Figure 2-1).

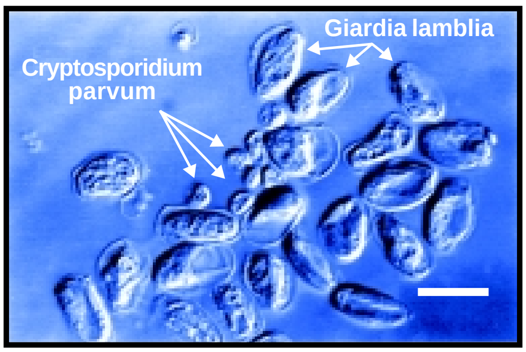


Figure 2-1. Photomicrograph of *Cryptosporidium parvum* oocysts and *Giardia lamblia* cysts. White Bar = 10 microns.

The continued occurrence of outbreaks of waterborne disease each year demonstrates that the quality and safety of drinking water can still be compromised by pathogens when it is not adequately treated. It is also likely that many other outbreaks occur but are either unrecognized or unreported. *Cryptosporidium* is a particular concern because it poses a risk to groups more susceptible to infection than the general population, such as those with weakened immune systems or preexisting diseases. Even in healthy individuals, ingestion of a small number of *Cryptosporidium* oocysts (a phase in *Cryptosporidium's* life cycle) may cause illness. This threat makes it critical to have sampling methods able to accurately and quickly detect the presence of *Cryptosporidium* in drinking water, and for all water treatment systems to be able to eliminate or inactivate the microbe.

To combat these threats, systems to treat drinking water have been in place for many years, taking advantage of both physical (sedimentation) and chemical (various disinfectants) treatment. A typical drinking water treatment system is shown in Figure 2-2. The use of chlorine to disinfect drinking water has been standard practice over the past 100 years, and has been a major factor in the dramatic decline of waterborne disease worldwide.

Although disinfectants have been highly successful in reducing the incidence of waterborne disease in humans, other concerns have been raised about the safety of disinfected water. For example, chlorine reacts with natural organic substances in source (untreated) water during treatment to form a number of potentially harmful chemical by-products termed disinfection by-products, or DBPs. It is now known that chlorine and alternative disinfectants such as chloramines, ozone, and chlorine dioxide produce hundreds of DBPs that end up in the drinking water supply at relatively low concentrations. Many of these substances have been shown to cause cancer and other effects in laboratory animals at very high levels of exposures. In addition, some epidemiology studies have reported slightly increased risks of cancer and adverse reproductive outcomes in populations exposed to disinfected drinking water, but a causal relationship has not been established.

The Safe Drinking Water Act (SDWA) Amendments of 1996 respond to these contamination problems by mandating that EPA appropriately address microbes and DBPs as well as other known or anticipated water contaminants. The Agency is developing new rules to establish additional standards that limit public exposure to microbial contaminants and DBPs. The overall goal and challenge of these new rules is to establish cost-effective approaches that minimize potential risks associated with DBPs without compromising the critically important need to control pathogenic microorganisms.

Given the uncertainty surrounding DBP-associated health risks, the severity of effects from certain microbes, and the potentially high costs of further regulation, EPA has designated drinking water as one if its highest research priorities. ORD's *Research Plan for Microbial Pathogens and Disinfection By-Products in Drinking Water* (www.epa.gov/ORD/WebPubs/final) describes the research needed to support the regulatory program of EPA's Office of Water and serves as the foundation for a major part of ORD's drinking water research program. ORD conducts research that provides critical information on drinking water health risks and human exposures to pathogens and DBPs, as well as on cost-effective water treatment processes and other means of reducing these risks. Although ORD is conducting research in many areas of drinking water, this chapter highlights research conducted on microbes and DBPs.

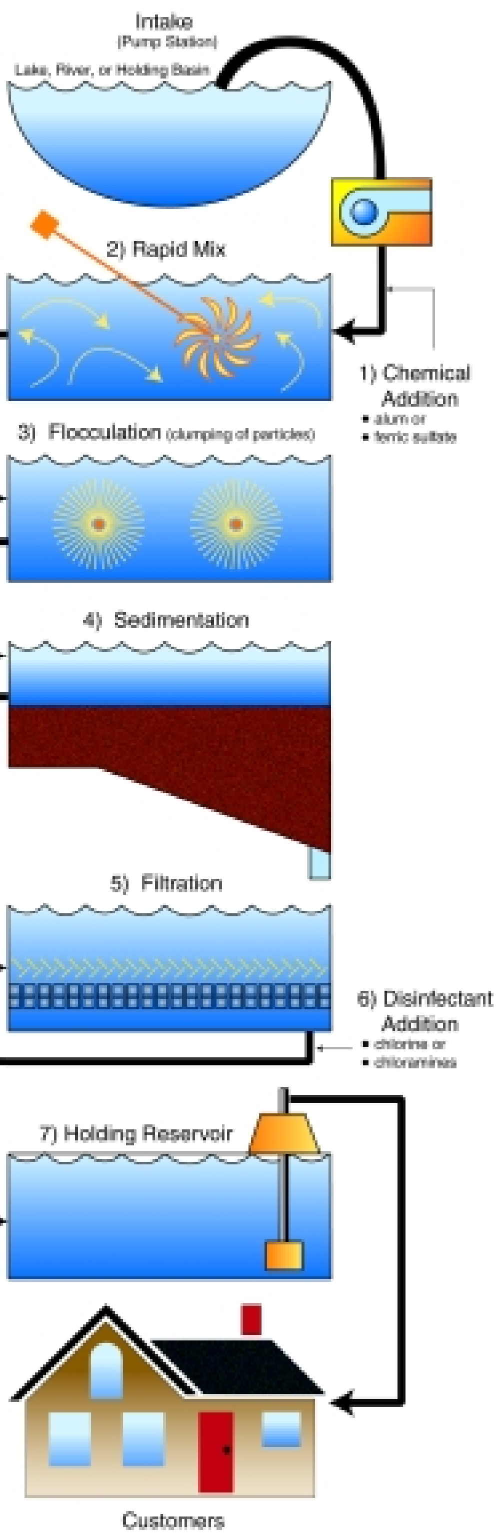


Figure 2-2. A typical water treatment plant system.

ORD's Drinking Water Research Program

As described in the Introduction, ORD uses the risk assessment/risk management framework to organize its research approach in solving scientific and technological problems. This framework is visually portrayed by the inner ring of Figure 2-3, with ORD's major microbial and DBP drinking water research and assessment activities depicted by the outer ring. ORD's drinking water research program is focusing on the following questions:

- **Exposure:** What methods are needed to adequately measure or estimate occurrence of pathogens and DBPs in drinking water? What is the occurrence of these contaminants, and to what levels are people actually exposed? What factors affect the contamination of drinking water by pathogens?
- **Health effects:** What are the pathogens and DBPs of greatest public health concern? What is the nature and magnitude of illness or disease associated with exposure to these agents?
- **Risk characterization:** How can the risks posed by pathogens, individual DBPs and mixtures of by-products be characterized? How can the risks associated with exposure to pathogens and DBPs be compared?
- **Risk management:** How effective are various treatment processes in minimizing the formation of DBPs and in removing pathogens? How can the quality of treated water be maintained in distribution systems? How can source water be adequately protected?

All major facets of ORD's drinking water research are subjected to external peer review. In addition to ORD's internal and extramural grants program, ORD is collaborating with other federal entities (e.g., the National Institute of Environmental Health Sciences and the Centers for Disease Control and Prevention), state health departments, and other research organizations such as the American Water Works Association Research Foundation.

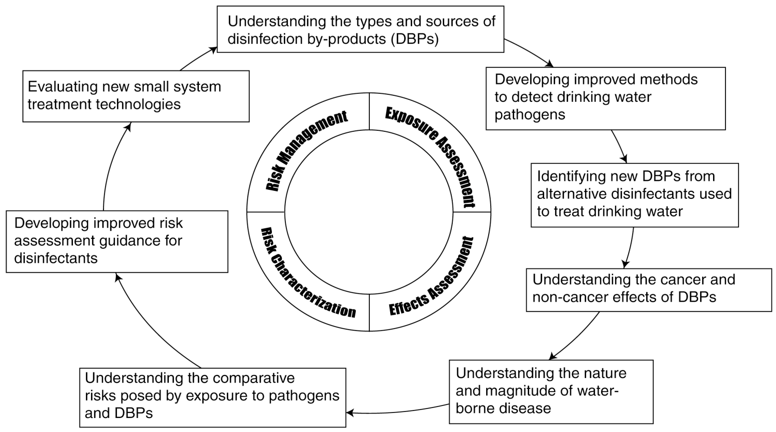


Figure 2-3. Some of the major research and assessment activities conducted by ORD in examining the health effects of microbial pathogens and DBPs in drinking water.

Recent Accomplishments

Developing Improved Methods to Detect Drinking Water Pathogens

The 1993 outbreak of *Cryptosporidium* in Milwaukee highlighted the importance of having sensitive and rapid methods to detect waterborne pathogens. In response to this need, ORD scientists, in consultation with other scientists in the field, developed and evaluated Method 1622, an improved method for detecting *Cryptosporidium* oocysts in source and drinking water. The previous method typically detected approximately 11% of *Cryptosporidium* oocysts added to a sample, whereas Method 1622 has an average detection rate of 38%. Method 1622 can be accessed on a website (www.epa.gov/nerlcwww/1622ja99.pdf).

An important limitation of available detection methods for *Cryptosporidium* is an inability to determine if the oocysts are viable (live) or infectious. This information is critical in assessing the public health significance of finding evidence of this pathogen in drinking water. Applying recent advances in the cell culture of *Cryptosporidium*, scientists at the Metropolitan Water District of Southern California under a STAR grant improved a method for determining oocyst viability and infectivity. The method involves: (1) recovery and purification of *Cryptosporidium* oocysts from the water samples using Method 1622; (2) inoculation of the oocysts onto human cells grown on slides; and (3) after incubation, detection of infected cells using molecular techniques. This method, combined with innovative molecular techniques, is a promising indirect approach for detection and quantification of infectious oocysts in drinking water.

Identifying New Disinfection By-Products from the Use of Ozone

Many drinking water treatment plants in the United States use disinfectants other than chlorine (particularly chlorine dioxide, ozone, or chloramines) to help control the risks from waterborne pathogens. However, uncertainty exists over the types and amounts of by-products produced from these alternative disinfectants, and their potential health risks. Of particular concern is the possibility that switching to alternative disinfectants to control microbial risks may actually lead to an increase in the risk associated with exposure to a new set of poorly characterized DBPs. Using specialized analytical techniques, ORD scientists have made considerable progress in identifying more DBPs that form when these alternative disinfectants are used (Figure 2-4).

Figure 2-4. ORD scientist prepares to inject a sample into the high resolution mass spectrometer to identify DBPs in drinking water.

Ozone can be an effective alternative disinfectant because fewer chlorinated by-products are produced. Ozone must be used in combination with a secondary disinfectant such as chlorine or chloramine, since residual concentrations of ozone do not remain in the treated water to provide continuous protection as does chlorine. Special concerns arise when ozone is used to treat water containing high levels of bromide, a naturally occurring substance present in source water in various parts of the United States. Ozonation of water containing bromide leads to the formation of bromate, which has been shown to cause cancer in laboratory animals. ORD scientists are conducting research to investigate the possible formation of other brominated by-products, which tend to be more toxic than related chlorinated by-products. These studies have found that elevated bromide levels contributed to an increase in brominated by-products following ozonation combined with chlorine or chloramine. Many of these DBPs had not been previously identified (Table 2-1), and they are now being prioritized for possible future health effects research to determine if any may be a concern to public health.

Understanding the Cancer Effects of Disinfection By-Products

Bromate. Bromate is one of several by-products regulated under the EPA's new Stage I Disinfectants/Disinfection By-Products (D/DBP) Rule, which established new standards that limit public exposure to disinfectants and certain DBPs in drinking water. Studies in one Japanese laboratory in the mid-1980s showed that bromate caused cancer in rodents. To more fully explore the public health risks of bromate, ORD scientists conducted a chronic exposure study in which rats and mice were exposed to various doses of bromate in their drinking water for up to two years. The animals were examined for tumors and other evidence of cancer at various intervals over the two year period. Bromate was found to cause cancer in the male rat at three different organ sites and to cause kidney tumors in the male mouse. EPA used the results of this study in its decision to establish a Maximum Contaminant Level Goal (MCLG) of zero for bromate. The MCLG is the level of a contaminant at which there would be no risk to human health. This value is used in the development of the Maximum Contaminant Level (MCL), a legally enforceable standard that represents the highest level of a contaminant that EPA allows in drinking water.

Disinfection By-Products
1, 1 - Dibromopropanone
1, 1 - Dibromo - 3 - chloropropanone
1, 1, 1 - Tribromopropanone
1, 1, 3 - Tribromopropanone
1, 1 - Dibromo - 3, 3 - dichloropropanone
1, 3 - Dibromo - 1, 3 - dichloropropanone
1, 1, 3 - Tribromo - 3 - chloropropanone
1, 1, 3, 3 - Tetrabromopropanone
1, 1, 1, 3 - Tetrabromo - 3 - chloropropanone
1, 1, 1, 3, 3 - Pentabromo - 3 - chloropropanone

Table 2-1. Family of recently identified disinfection by-products (Halopropanones).

Brominated trihalomethanes. The trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane and bromoform) are among the most prevalent DBPs in chlorinated drinking water. These substances are currently regulated by EPA as a class of compounds under the new Stage I D/DBP Rule. The trihalomethanes have been shown to cause cancer at high doses in laboratory animals and have also been associated with low risks of cancer in several epidemiology studies. One of the most important avenues of investigation for trihalomethanes is the potential mechanism(s) by which they cause cancer, since this will help clarify if and how these substances pose a risk to humans. Previous research suggests that brominated trihalomethanes may be more carcinogenic than similar by-products containing chlorine (e.g., chloroform), but the reasons for these differences are unknown.

Some insights into this issue are being provided by new ORD findings on how the brominated trihalomethanes are metabolized. In animals and people, typically one or more metabolic pathways exist that transform environmental toxicants into metabolites that can be eliminated from the body, but in some cases the metabolites are more harmful than the parent chemical. ORD scientists have identified one such potentially harmful pathway that is active for brominated trihalomethanes, but not chloroform. This pathway involves an enzyme, glutathione S-transferase theta, and may result in damage to cell DNA, increasing the likelihood that the affected cell may become cancerous (Figure 2-5). An analogous enzyme is found in humans, and therefore a similar pathway is likely to be active in people. Moreover, the production of glutathione S-transferase theta is known to vary greatly among

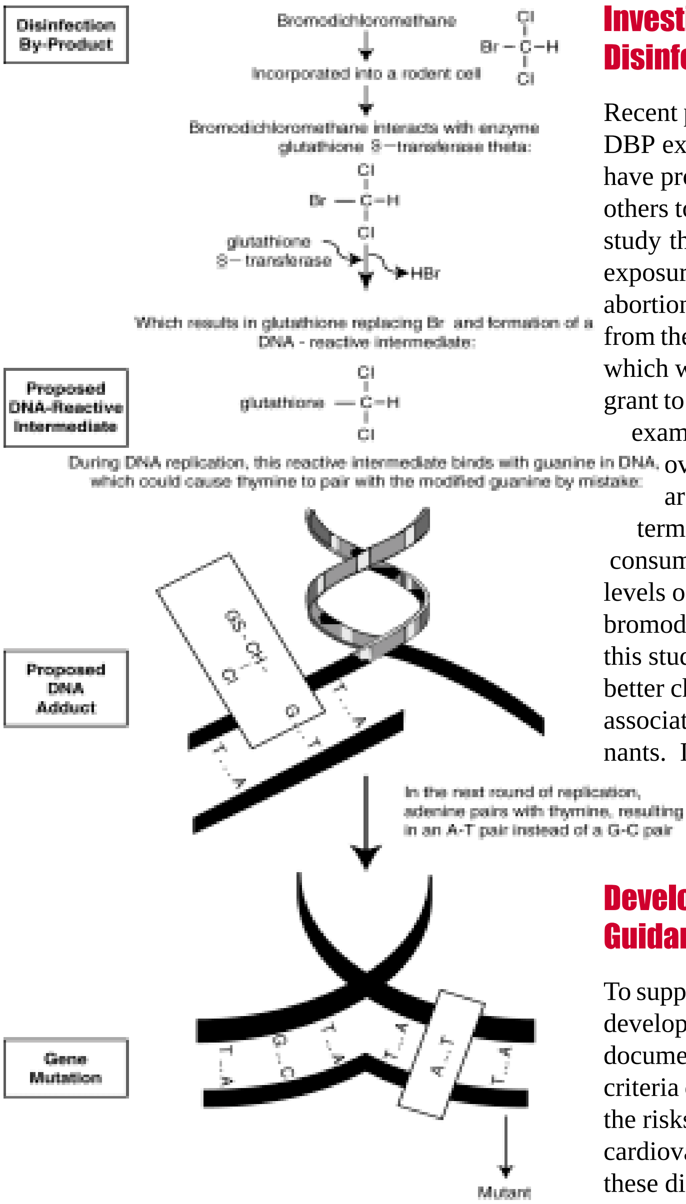


Figure 2-5. Metabolic pathway by which the DBP bromodichloromethane may cause DNA damage.

humans, which could mean that individuals differ in their susceptibility to cancer from exposure to the brominated trihalomethanes in drinking water. Understanding these metabolic processes in both animals and humans will provide a better scientific foundation for the risk assessments of these contaminants, and could ultimately influence risk management strategies to limit exposures to the DBPs that pose the highest concern.

Investigating Noncancer Health Effects of Disinfection By-Products

Recent publications in the scientific literature on DBP exposures and adverse reproductive effects have prompted a concerted effort by EPA and others to study this issue. In 1998, a landmark study that evaluated the relationship between exposure to trihalomethanes and spontaneous abortion in women was published by scientists from the State of California. This investigation, which was partially supported by ORD through a grant to the California Public Health Foundation, examined health and exposure data collected for over 5,000 pregnant women living in three areas of California. An increased risk of early term miscarriage was observed in women who consumed large amounts of water containing high levels of total trihalomethanes and bromodichloromethane. Although not conclusive, this study provided important new information to better characterize the potential health risks associated with exposure to drinking water contaminants. It also highlighted the need for additional research to replicate the findings as well as refine how exposure is characterized in these types of studies.

Developing Improved Risk Assessment Guidance for Disinfectants

To support EPA's Stage I D/DBP Rule, ORD developed comprehensive risk assessment criteria documents for chlorine and chloramine. Each criteria document provided guidance for estimating the risks of cancer and other health effects (e.g., cardiovascular disease) associated with exposure to these disinfectants. The criteria documents were peer reviewed by EPA's Science Advisory Board. The risk assessments concluded there was no significant evidence that exposure to chlorine or chloramine in drinking water caused cancer in humans, produced long-term toxic effects at levels found in drinking water, or caused long-term noncancer health risks such as reproductive failure, cardiovascular disease, liver toxicity, or developmental toxicity. These results served as the scientific basis for establishing the maximum residual disinfectant goals for chlorine and chloramine in the Stage I D/DBP Rule.

Evaluating New and More Cost-Effective Small System Treatment Technologies

Some issues of concern for small community drinking water systems in the United States are lack of appropriate, readily available technologies at affordable operation and maintenance costs. Nearly 90% of the water quality violations under the SDWA occur in small systems and are related to microbiological contamination of the water. ORD is evaluating a variety of alternatives to conventional water treatment systems that are effective, simpler, and less expensive to operate and maintain in order to mitigate many of these problems.

ORD investigated several types of filtration systems to determine their effectiveness in removing harmful microorganisms from drinking water. ORD scientists found that the ability of the filtration systems to remove *Cryptosporidium* was highly variable. Bag filtration systems demonstrated a wide range of effectiveness, whereas removal with cartridge filtration was more reliable. Ultrafiltration (Figure 2-6) removed most of the *Cryptosporidium*, although imperfections in manufacturing and design seriously reduced effectiveness.

ORD scientists also demonstrated that small, inert, plastic beads called microspheres are the most accurate and precise *Cryptosporidium* surrogates for safer, quicker, and less-expensive pilot testing of the different types of filters. These surrogates will make it easier to evaluate filtration technologies, and help ensure that the alternative technologies are operated properly by local entities, particularly in small communities.

Where Do We Go From Here?

The challenges that lie ahead for the drinking water research program are broad, covering a wide range of issues and contaminants that are the focus of either current or future regulatory decision making under the Safe Drinking Water Act Amendments of 1996. As ORD carries out its drinking water research program, it will continue to use the risk assessment/risk management framework depicted in Figure 2-3 to organize and integrate its research. Research on DBPs and microbial pathogens currently underway builds on past research and accomplishments.

For example, in the area of exposure assessment, development of more reliable and sensitive methods to measure very low levels of bromate and aldehyde by-products (important ozone DBPs) in treated

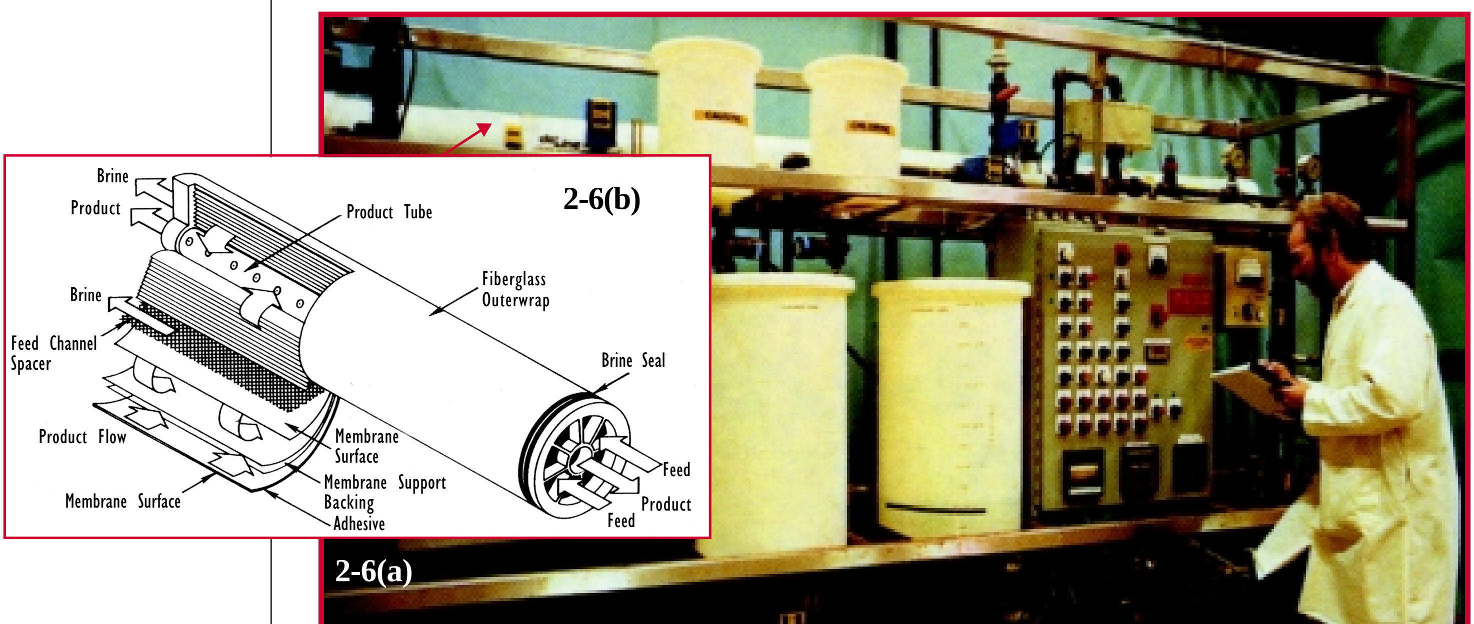


Figure 2-6(a): ORD scientist testing ultrafiltration membrane package plant. **2-6(b)** Inset is a cut-away drawing of the spiral-wound membrane, which is placed in the horizontal white tube at the top of the stainless steel structure. Three 8-inch by 40-inch membranes are loaded into the white tube like batteries in a flashlight. Water enters the tube from the right, passes through the membranes, and exits the tube on the left.

water is nearing completion. These methods can then be used for regulatory compliance monitoring of bromate and aldehydes. Studies are also being conducted to develop improved detection methods for viruses (e.g., echovirus, coxsachievirus) that may be responsible for waterborne outbreaks of acute nonbacterial gastroenteritis.

In addition to improving detection methods, ORD researchers are evaluating laboratory tests to accurately determine the characteristics of certain bacteria known to grow on filtration materials used for treating water and collect on the surfaces of pipes in the drinking water distribution systems (known as biofilms). Although these bacteria are not known to affect healthy individuals, they may pose a risk to people whose resistance to infection is impaired. Research is also being conducted to determine the most effective means for controlling the growth of bacteria in the distribution system by using alternative disinfectants and pH control.

Health effects research is continuing to investigate the potential reproductive and developmental effects of priority DBPs. Follow-up research is being conducted on by-products from selected chemical classes (e.g., haloacetic acids) that may be of greater concern for these kinds of effects. ORD scientists are also reevaluating the California populations included in a spontaneous abortion study using an improved exposure assessment to address some of the weaknesses of the previous study.

In addition, ORD is collaborating with the Centers for Disease Control and Prevention to analyze data for 1997-1998 on the occurrence and causes of waterborne disease outbreaks in the United States. Goals include characterizing the epidemiology of waterborne disease for this period, and identifying water treatment system deficiencies and specific contaminants responsible for the outbreaks. ORD is also conducting studies in several parts of the United States to evaluate the occurrence of endemic waterborne disease (i.e., a “non-epidemic” level of disease that may be attributable to drinking water but not reported as an outbreak).

In the area of risk management research, ORD scientists are continuing to examine the effectiveness of alternative disinfectants such as ozone to inactivate *Cryptosporidium* and reduce harmful DBPs without creating biofilm growth problems in the distribution system. A manual for state drinking water agencies will be prepared summarizing the most recent developments. In addition to research on drinking water distribution systems, ORD scientists are developing improved methods for estimating the vulnerability of ground water systems to viral contamination. Research includes evaluating important hydrogeological, geochemical, and microbiological factors affecting the transport and survivability of viruses in the subsurface to more accurately characterize and predict viral contamination of ground water.

3. Advances in Risk Assessment

Risk Assessment Overview

Introduction to Risks and Risk Assessment

Each day we face a multitude of risks that vary both in their likelihood of occurrence and in how much we can control them. For example, depending on our jobs and hobbies, we may be at risk from accidents and injuries. Each of us also faces environmental risks as we are exposed to pollutants in the air we breathe, the water we drink, and the food we eat. Although we may not realize it, each of us acts to evaluate and control many of the risks we face. Before we set out in our car on a snowy day, for instance, we may *assess* the road conditions and take actions to *manage* the risks by driving slowly and wearing a seatbelt. Government agencies and other institutions also endeavor to understand and control risks, but they often use more formal and structured processes known as risk assessment and risk management.

Risk can be defined as a measure of the likelihood that a given hazard will cause harmful events to occur, such as illness and death in people and wildlife or damage to ecosystems and property.

Risk assessment is a tool for gathering and organizing the best available information so that risks can be understood. As described in the introduction to this report, risk assessment is commonly divided into four phases following an approach developed by the National Academy of Sciences. These are hazard identification, dose-response assessment, exposure assessment, and risk characterization. *Risk management* is the process of evaluating information from a risk assessment—as well as factors such as economic and social considerations—to decide what should be done about the risks. Figure 3-1 depicts the risk assessment and risk management processes.

When applied to chemicals, risk assessment examines the types of adverse health effects that might occur in humans and wildlife following chemical exposure (hazard identification), how they vary with the degree of exposure (dose-response), and the degree to which exposure actually occurs (exposure assessment). Combining this information enables the overall risk to be described for decision makers (risk characterization). Risk management involves deciding what actions, if any, are needed to prevent or reduce the risk, such as limiting pollutant emissions.

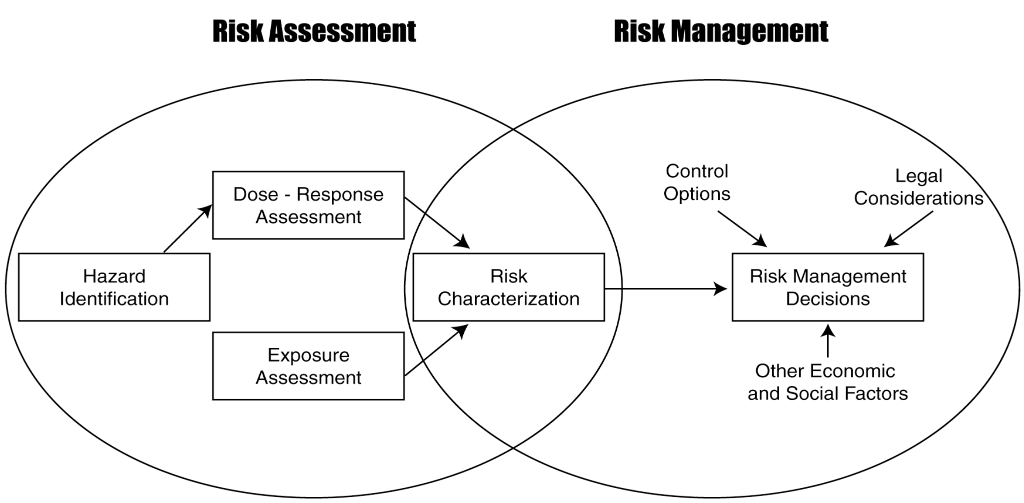


Figure 3-1. As commonly described, risk assessment consists of four phases, culminating in risk characterization. The findings of the risk assessment are considered along with several other factors in making risk management decisions.

Use of Risk Assessment at EPA

Many of the laws that govern EPA programs require the use of risk assessment. EPA applies risk assessment to a variety of regulatory issues including toxic chemical control, pesticide registration, hazardous waste cleanups, and the setting of air, water, and soil standards. Given the costs that are required for activities such as cleaning up hazardous waste sites, it is important that EPA's risk assessments provide the information needed for setting priorities for cost-effective responses to environmental problems. Even though EPA's various mandates may require different risk management approaches, EPA strives to use consistent, publicly-reviewed methods for conducting risk assessment across the Agency. Consistency in risk assessments contributes to their more efficient development, less confusion on behalf of affected parties, and better regulatory decisions.

In applying risk assessment to regulatory decision making, EPA analyzes all available scientific evidence in order to evaluate the relationship between exposure to environmental agents and the potential to cause harm. The concerns addressed by a risk assessment may include health effects such as reproductive and developmental abnormalities, cancer, and neurological effects, as well as ecological effects such as species extinction, loss of habitat and other forms of ecosystem damage.

Challenges in Risk Assessment

Although risk assessment provides a structured framework for rational regulatory decision making, it is not without controversy. One of the most difficult – and frequent – risk assessment challenges faced by EPA is how to handle uncertainties that arise when environmental exposures of concern differ greatly from the situations in which risks have been scientifically studied. For some kinds of hazards, risks can be estimated directly from readily available sources, such as risks of dying in a plane crash or from lightning. However, for many of the risks EPA deals with, such as risks of dying of cancer from chemical exposure, risks are much more difficult to estimate. Much of the information about a chemical's potential toxicity may be restricted to laboratory animal studies. Even if health effects have been confirmed in people, the information typically is for highly exposed subgroups such as industrial workers. In the case of new chemicals under consideration for approval by EPA, little or no human data may exist at all.

As a result, risk assessors must extrapolate from the conditions under which risk information has been collected to the actual conditions of human exposure. To bridge information gaps, EPA and other regulatory agencies use what are known as *default assumptions*. Default assumptions are inferences based on general scientific knowledge of the phenomena in question and are also matters of policy concerning the appropriate way to bridge uncertainties. Examples include standard approaches for extrapolation from laboratory animals to humans and from the high exposures of laboratory and occupational studies to the lower exposures experienced under environmental conditions. For instance, in the absence of data to the contrary, EPA assumes that humans are more sensitive to chemicals of concern than laboratory animals. While necessary, default assumptions come under frequent criticism for either being overly protective or insufficiently protective of human health and the environment.

Several advisory panels have examined the risk assessment approaches used within regulatory agencies and made a number of recommendations for improving the process. Most recently, the National Research Council (*Science and Judgment in Risk Assessment*, 1994) and the Commission on Risk Assessment and Risk Management (*Risk Assessment and Risk Management in Regulatory Decision-Making*, 1997) provided recommendations to EPA. In summary, these advisory groups concluded that the scientific foundation that forms the basis for EPA's approach to risk assessment should be further strengthened through a long-term research program to reduce EPA's reliance on default assumptions and by developing information on cumulative risk.

> "The quality of risk analysis will improve as the quality of input improves. As we learn more about biology, chemistry, physics, and demography, we can make progressively better assessments of the risks involved. Risk assessment evolves continually, with reevaluation as new models and data become available."
>
> *Science and Judgment in Risk Assessment* (National Research Council, 1994)

ORD's Program to Improve Risk Assessment

In response to these continuing challenges and the recommendations from scientific organizations, ORD is carrying out a major program to improve both human health and ecological risk assessment.

In carrying out this program, considerable emphasis is placed on scientific peer involvement and peer review. In addition, ORD is collaborating with other federal agencies, states, international organizations and professional societies to harmonize risk assessment approaches on a national and international scale.

One major component of ORD's risk assessment program is the development of risk assessment guidance, in partnership with EPA's regulatory offices, to foster consistency across EPA. To date, risk assessment guidelines have been developed addressing cancer, mutagenicity, developmental and reproductive effects, neurotoxicity, exposure, chemical mixtures, and ecological effects. Periodically, these guidelines are updated to reflect current knowledge and emerging issues. Another aspect of ORD's program is the continual refinement of existing exposure and effects data, models and methods. As the scope and quality of data are improved, ORD is able to improve the various models and methods used in risk assessment, which in turn improves the overall accuracy of a risk assessment. Through this research, ORD can reduce the uncertainty in risk assessments and the need to rely on default assumptions. Finally, ORD also conducts risk assessments. These assessments generally either serve as prototypes demonstrating new scientific approaches or address Agency needs that span many different programs or are particularly contentious and precedent-setting.

Recent Accomplishments

Development of Risk Assessment Guidance

EPA risk assessment guidance is prepared by the Risk Assessment Forum, which is staffed by ORD and brings together panels of experts from across the Agency. Not to be confused with EPA's testing guidelines (which provide specific guidance on how to conduct toxicity and other tests), the risk assessment guidelines set forth Agency-wide approaches for assessing risks. During 1997 to 1998, the following guidelines and guidance were published by the Forum.

Guidelines for Ecological Risk Assessment

Ecological risk assessment evaluates whether adverse ecological effects may occur or are occurring from exposure to one or more chemical, biological, or physical stressors (such as pollutants or habitat loss). In 1992, EPA proposed its first principles and terminology for the ecological risk assessment process in the *Framework for Ecological Risk Assessment*. Other materials followed, such as ecological assessment case studies. The *Guidelines for Ecological Risk Assessment* (www.epa.gov/ncea/ecorsk.htm), published in May 1998, build on the earlier efforts. Developed to increase consistency and improve the quality of ecological risk assessments within EPA, the Guidelines describe EPA's current scientific thinking and approaches for conducting ecological risk assessments.

The Guidelines provide examples of how ecological risk assessment can be applied to a wide range of situations, such as hazardous waste clean-up, new chemical and pesticide registration, and watershed management. Rather than specifying techniques and methods for ecological risk assessment, they describe general approaches that can be used and their strengths and weaknesses. Figure 3-2 depicts the overall framework for ecological risk assessment presented in the Guidelines. Although the Guidelines are primarily intended for use within EPA, other government agencies and the interested public will benefit from understanding EPA's approach to ecological risk assessment.

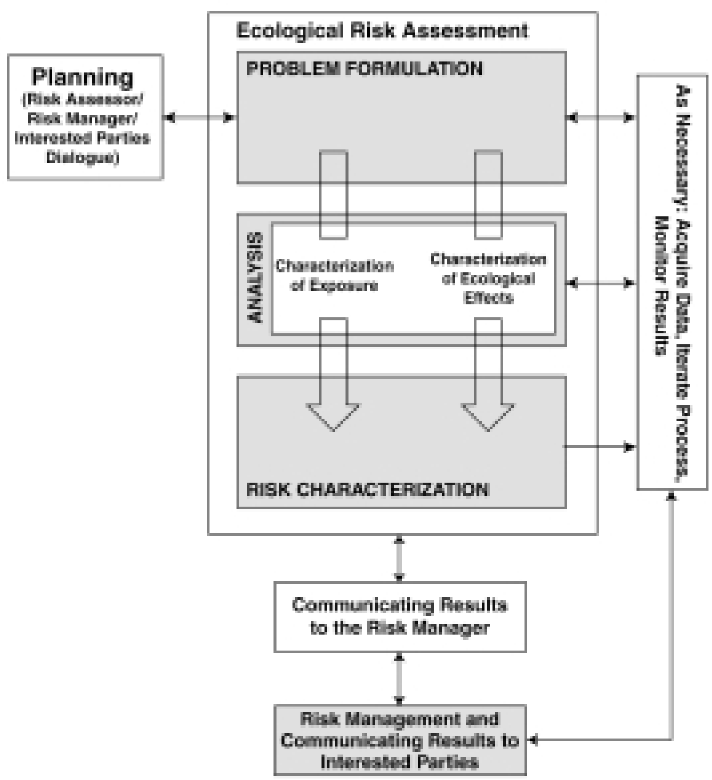


Figure 3-2. The framework for ecological risk assessment.

Guidelines for Neurotoxicity Risk Assessment

The nervous system (composed of the brain, spinal cord, and nerves) regulates the flow of information in the body and controls bodily functions. Neurotoxicity refers to a toxic effect on the nervous system after exposure to a chemical, physical, or biological substance. Toxic effects that occur, such as changes in muscle coordination, paralysis, seizures, or behavioral changes, vary depending on the amount of exposure and the region of the nervous system affected (Figure 3-3). Incidents of severe and irreversible nervous system damage in people following exposure to chemicals such as mercury have underscored the health risks that neurotoxic agents can pose. EPA developed the *Guidelines for Neurotoxicity Risk Assessment (*www.epa.gov/ncea/nurotox.htm*)* to provide a sound scientific basis and promote consistency in conducting neurotoxicity risk assessments. The Guidelines:

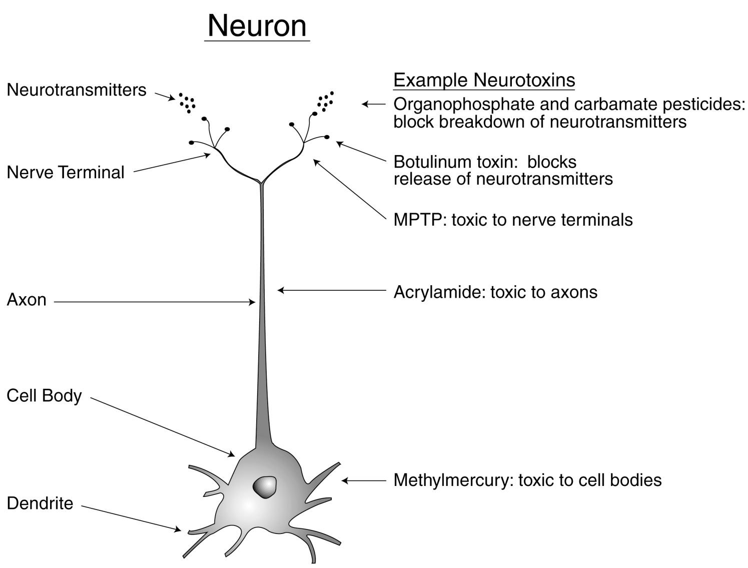


Figure 3-3. Examples of neurotoxicity. Nerves are made up of cells called neurons. Neurons receive impulses from other neurons through dendrites, transmitting signals along axons to nerve terminals, where neurotransmitters are released. Neurotransmitters stimulate adjacent neurons or, in the case of motor neurons, stimulate muscles. Neurons are vulnerable to toxic agents that can act on various stages of the signal pathway; a few examples are shown here.

- Outline the scientific basis for evaluating effects from exposure to neurotoxicants and discuss how to evaluate data from human and animal studies.
- Note the special vulnerability of the nervous systems of infants and children to chemicals and provide guidance on interpreting developmental and reproductive studies that involve the nervous system.
- Characterize the health-related data base for neurotoxicity risk assessment.
- Describe calculations and approaches for some specific elements of neurotoxicity risk assessment, such as estimating the exposure level below which adverse effects will not occur (the *reference dose*).

Guiding Principles for Monte Carlo Analysis

Though risk assessments are indispensable tools for EPA, they have limitations in how accurately they reflect the true risks that people or ecosystems face. Two major reasons for their limitations are *uncertainty* and *variability*. Uncertainty refers to lack of knowledge about particular factors that are important in risk assessment. For example, any given technique for measuring pollution levels has inherent uncertainties and the amount of a pollutant required to cause a specific health effect usually is also uncertain. Variability refers to true diversity among individuals or properties assessed. For instance, people vary in their body weights, age, and susceptibilities to toxic chemicals. Also, the amount of pollution emitted and weather conditions that affect pollutants in the environment vary over time.

A recent trend in risk assessments has been to enhance their usefulness and validity by more thoroughly describing the variability and uncertainty in the exposure or risk estimates. One approach to accomplishing this is known as probabilistic analysis, which includes a technique known as Monte Carlo Analysis. In probabilistic analysis, statistical techniques and computer simulations are used to generate a range of risk values, rather than a single "point estimate" of the average or "worst-case" risk (Figure 3-4). Expressing risk as a range is much more informative than a single number, and can help identify groups of individuals who may be most at risk from a particular chemical.

In 1997, EPA prepared the first Agency-wide principles for the use of probabilistic analysis in risk assessments, the *Guiding Principles for Monte Carlo Analysis* (www.epa.gov/ncea/mcpolicy.htm). The principles represent an important scientific advance in the way EPA conducts risk assess-

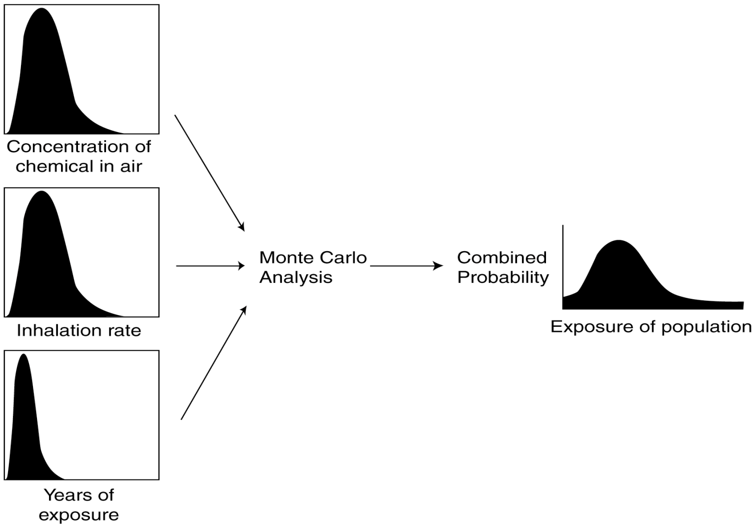


Figure 3-4. Simplified example of the use of Monte Carlo Analysis to estimate the exposure of a population to an air pollutant. Expressing exposure (or risk) in a range is more informative than generating a single value to estimate exposure for an entire population.

ments. Highlights of the principles include recommendations that analyses should:

- Clearly state the purpose and scope of the assessment and the methods used.
- Discuss any highly exposed or sensitive groups, such as children.
- Describe what went into the risk calculations and results.
- Compare distributions of exposures to health-based values, such as drinking water standards.

Assessment of Thyroid Tumors

In 1998, EPA published the *Assessment of Thyroid Follicular Cell Tumors* (www.epa.gov/ncea/thyroid.htm), which describes the procedures the Agency will use in assessing the risks to people from chemicals found to cause thyroid cancer in laboratory animals. The guidance is noteworthy not only for its contribution to assessing thyroid cancer risks, but also because it presents an official EPA position on when it is appropriate to deviate from an important default assumption about cancer risks. Historically, EPA assumed that as exposure to a carcinogen decreases, the risk also decreases but does not disappear entirely until the exposure ceases, which is known as a *linear extrapolation* approach to estimating risks (Figure 3-5). Under the guidance, EPA will continue to use this approach if a chemical causes thyroid cancer by damaging DNA (i.e., it is mutagenic) or if no data are available about how it causes cancer. The guidance also clearly explains the criteria that must be met before a *nonlinear* extrapolation approach can be considered. Such an approach presumes a *threshold* exists below which cancer is unlikely to occur.

The guidance bases its conclusions on improved scientific understanding of how chemicals cause thyroid cancer. Though the only verified thyroid carcinogen in humans is ionizing radiation, thyroid tumors are fairly common in long-term studies of chemicals in rodents. The thyroid gland sets the metabolic rate of the body's cells, based on a hormone feedback loop regulated by the pituitary gland. Long-term exposure to some chemicals can disrupt this feedback loop, leading to thyroid tumors. EPA's guidance concludes that brief, low-level exposures to chemicals, however, would not be likely to cause sustained disruption of the thyroid-pituitary loop and thus would not pose cancer risks in people. The guidance applies only to thyroid tumors, not cancer of other organs.

Improvement in Risk Assessment Methods and Models

In addition to preparing guidance on how to conduct risk assessments, ORD develops methods, models, and data that can be adapted for individual risk assessments. Two recent accomplishments include the following:

Exposure Factors Handbook

Assessing exposure is one of the major steps in performing a human health risk assessment. To accurately assess exposure, not only must the concentrations of the chemical of concern be ascertained, but the activities that lead individuals to come in contact with the chemical must be understood as well. Examples include the amount of water people drink, how much air they breathe, where they work, and the amount of time they spend outdoors. Collectively, these activities and characteristics are termed *exposure factors*. In August 1997, ORD advanced the state-of-the-science for exposure assessment by publishing a revised and expanded *Exposure Factors Handbook* (www.epa.gov/nceawww1/exposure.htm), originally issued by ORD in 1989.

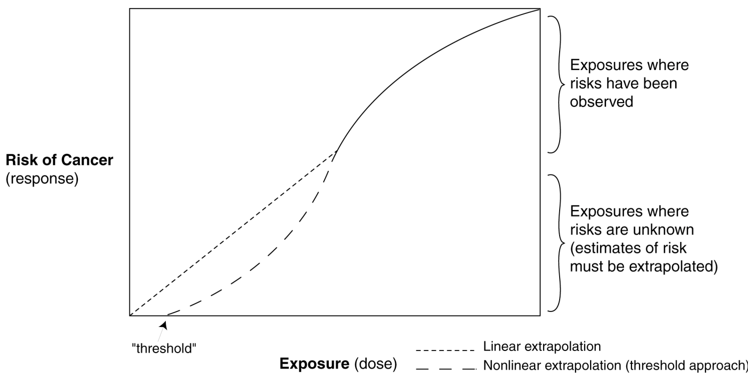


Figure 3-5. Linear and nonlinear extrapolation of cancer risks. Studies of risks from exposure to chemicals often find that cancer risks decrease as exposure drops, but risks at low levels of exposure are difficult to measure and frequently unknown. Historically, risk assessors have usually used a linear extrapolation for carcinogens to estimate low exposure risks. EPA's thyroid tumor guidance discusses when a nonlinear approach, which assumes a threshold of exposure below which cancer risks do not exist, may be appropriate.

Among the many new sets of information in the revised handbook are data on consumer product use, drinking water rates for children, and daily intake of food by region and age.

The Handbook recommends exposure factors to be used in estimating chemical exposure for different age and gender groups, including national means and ranges of values for water and food ingestion, body weights, and inhalation rates. Factors important in determining contaminant exposure for potentially sensitive groups, such as pregnant women and children, are included. For example, the Handbook estimates how much drinking water is ingested by pregnant women, children, and others each day (Table 3-1). As the only authoritative source for peer-reviewed exposure factors, the Handbook has become an indispensable resource for risk assessors within and outside of EPA.

National Human Activity Pattern Survey

Daily activities, such as smoking, driving, and time spent in different locations, make up an important set of exposure factors discussed in ORD's *Exposure Factors Handbook*. They are vital to exposure assessment because they impact how often, how long, and how many pollutants people are exposed to. Mathematical exposure models have been developed to incorporate daily activity information into risk assessments, but have been limited by the lack of sufficient data on the wide range of activities people engage in. The ORD-sponsored National Human Activity Pattern Survey (NHAPS) fills this vital human exposure research need by providing comprehensive human activity and location information on a national level that can be used in risk assessments. NHAPS findings have been incorporated into the *Exposure Factors Handbook* and into ORD's Consolidated Human Activity Database, a compendium of ten human activity databases available on the Internet at www.epa.gov/chadnet1/index.html.

NHAPS consisted of a two-year telephone survey of more than 9,000 individuals carried out by the University of Maryland Survey Research Center to collect detailed information on the time, location, and nature of activities relevant to estimating pollutant exposure. Technical reports and journal articles describing the findings of the Survey were completed in 1998. Participants reported all activities for specific locations (e.g., at home vs. in a car) for the prior 24-hours, as well as information on activities that can increase chemical exposure, such as smoking, cooking, washing, or cleaning. Key findings of the Survey (see also Figure 3-6) included:

- The largest amount of time was spent indoors in homes (69%).
- Almost 6% of time was spent in vehicles.
- Nearly 8% of time was spent outdoors.
- Children, particularly those of school-age, spent more time outdoors than adults. Children and the elderly spent less time in vehicles than younger and middle-age adults.

Precedent-Setting Risk Assessments: Mercury Report to Congress

In addition to preparing guidance on how to conduct risk assessments and generating underlying data and methods for risk assessment, ORD conducts selected risk assessments that set a precedent for EPA by testing innovative approaches or have national implications that cut across many Agency programs. A noteworthy example is the eight-volume Mercury Report to Congress mandated by the Clean Air Act that EPA issued in December 1997. This report was a multi-year effort, involving scientists from across EPA, to evaluate the impact of air emissions of mercury on

Summary of Drinking Water Intake Rates		
Age Group/Population	**Average Amount Consumed Per Day (Liters/ Day)**	**Amount Consumed Per Day Per Unit of Body Weight (Milliliters/Kilogram - Day)**
<1 year	0.30	44
1 - 10 years	0.74	35
11 - 19 years	0.97	18
Adults	1.4	21
Pregnant Women	1.2	18
Adults in high activity/ hot climate conditions	0.21 to 0.65 liters/hour, depending on temperature and activity level	

Table 3-1. When assessing risks from contaminants found in drinking water, risk assessors need information on how much water people consume. This table presents the drinking water intake values that the *Exposure Factors Handbook* recommends be used in risk assessment (excerpted from Table 3-30 of the Handbook). Drinking water intake is one of many exposure factors presented in the Handbook.

human health and the environment and review available control technologies. ORD contributed a series of innovative models used in the report that examine atmospheric and water transport, bioaccumulation, exposure, and health effects of mercury.

Mercury is considered a serious concern, because it persists and accumulates in the environment and can damage the nervous system of humans and wildlife, especially during development. Atmospheric emissions can reach waterways as a result of rainfall or runoff and then build up as methylmercury in the tissues of predatory fish that feed on contaminated smaller fish (Figure 3-7). Contaminated fish also can be eaten by people and wildlife. The report estimated that about 158 tons of mercury were emitted into the air in 1995 from all U.S. industrial sources. Major emission sources include electric utilities, incinerators, industrial boilers, and chloralkali plants. Consumption of contaminated fish is the greatest source of human exposure to mercury. The report noted that, given the mercury levels generally found in commercial fish, it is safe to eat fish and other seafood in moderation from grocery stores and restaurants. Pregnant women should heed state and federal fish advisories for mercury due to risks to the developing fetus.

Where Do We Go From Here?

ORD is continuing work in the three areas described above: developing risk assessment guidance, improving methods and data for risk assessment, and preparing precedent-setting risk assessments.

One important project involves updating the *Guidelines for Carcinogen Risk Assessment*, which EPA originally published in 1986. Since that time, significant scientific progress has been made in understanding how cancer develops, and EPA's experience with the 1986 Guidelines has revealed several limitations in their approach to cancer risk assessment. EPA proposed revised guidelines in April 1996 and is now preparing final guidelines. Historically, EPA has concentrated on determining how many tumors a chemical induces at certain doses. The proposed revisions give greater weight to accounting for the molecular events leading up to tumor formation – information known as *mode-of-action* data. Expanding the breadth of information considered will strengthen the biological foundation of cancer risk assessments and reduce uncertainties. Among the other proposed changes are providing additional guidance for assessing risks to potentially susceptible populations, such as children.

Another risk assessment guidance project underway is the development of guidance for Cumulative Risk Assessment. To date, most risk assessments have evaluated one chemical at a time, or at most a few related chemicals. However, several recent reports from the National Academy of Science and others, as well as the 1996 Food Quality Protection

Act, have called on federal agencies to do more to account for the cumulative exposure to multiple chemicals. In the real world, human populations are exposed to many chemicals and other stressors simultaneously, which could result in health risks that differ from what would be expected considering only single chemical exposures. Chemicals that cause similar forms of toxicity, for example, might lead to risks that should be added together in estimating the likelihood of an adverse health effect. The guidance under development is intended to provide EPA with a consistent and scientifically credible approach to assessing cumulative risk both for multiple stressors and for multiple routes of exposure (e.g., inhalation, ingestion, exposure through the skin).

A notable ORD project that is expected to improve the ability of the Agency to carry out cumulative risk assessments is the National Human Exposure Assessment Survey, or NHEXAS. Begun in 1993, the effort is examining the feasibility of conducting human exposure studies for multiple chemicals for multiple routes of exposure at a regional scale. The study is focusing on actual exposures of individuals to contaminants in their daily lives. Human exposures to metals, pesticides, and other chemicals were measured in the air, food and beverages, and in residential soil and dust. Levels of chemicals were measured in blood and urine samples, and volunteers completed questionnaires to help identify their activity patterns and possible sources of exposure. Hundreds of volunteers participated in three interrelated studies located in Arizona, the Midwest, and Maryland. As the results are analyzed over the next several years, they should prove useful in understanding chemical exposures of concern as well as aiding in planning and conducting future exposure studies.

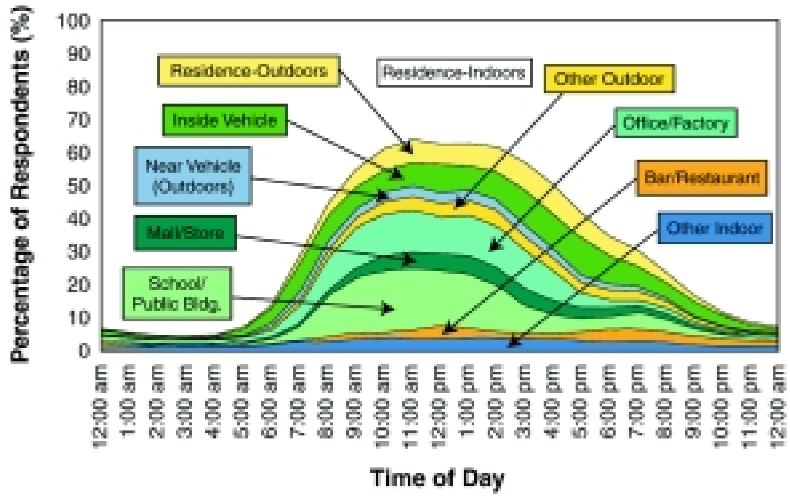


Figure 3-6. Plot showing the percentage of respondents reported being in one of ten different locations for different times during the 24-hour day, from the National Human Activity Pattern Survey.

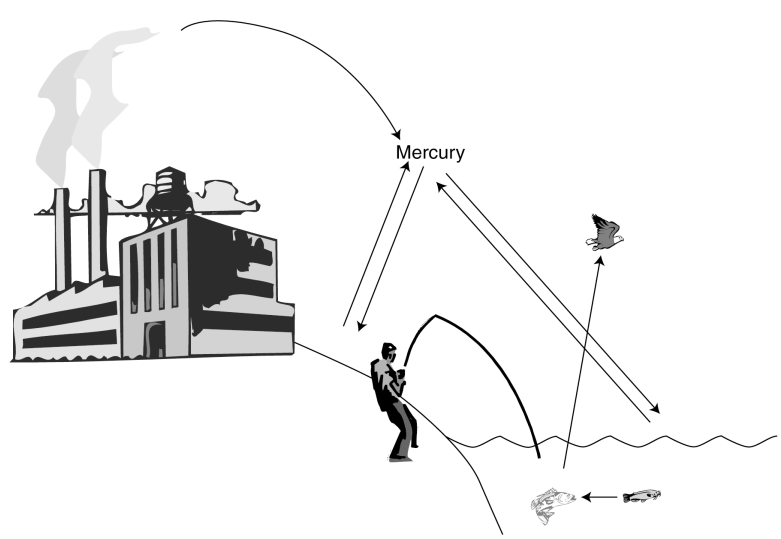


Figure 3-7. Transport of mercury in the environment. Mercury is emitted into the air from coal-fired utility boilers, municipal waste combustors, and a variety of other sources. It subsequently is deposited on the land and water. After reaching bodies of water, it can accumulate in the tissues of predatory fish, which become the principal source of human mercury exposure.

Finally, ORD continues to prepare precedent-setting and cross-cutting risk assessments. Projects underway include a comprehensive reassessment of the risks of dioxin, Air Quality Criteria Documents for pollutants such as particulate matter and carbon monoxide, a review of the health risks of diesel engine emissions, and a number of Agency consensus positions on other chemicals that are being compiled on the Internet-accessible Integrated Risk Information System (www.epa.gov/iris).

4. Mid-Atlantic Integrated Assessment (MAIA)

Since EPA was founded in 1970, the nation has devoted enormous effort to cleaning up pollution and protecting the environment. Businesses and government agencies have spent millions of dollars to carry out and comply with laws designed to protect the environment such as the Clean Air Act, Safe Drinking Water Act, Superfund, and the Endangered Species Act, not to mention state and local laws and initiatives. Over this same time period, the U.S. population has grown by one-third to more than 270 million people and economic activity has accelerated. Rising consumption of resources such as water, forests, and fossil fuels has the potential to increase pollution and deplete future supplies if not they are not managed sustainably. Overall, is the environment getting better or worse? Why?

These questions may sound simple, but answering them is not, in part because "the environment" encompasses such a wide range of natural components. Over the past few decades most environmental monitoring programs have focused on relatively limited geographic areas or narrow measures of environmental quality, such as commercial fish stocks or concentrations of major air pollutants. Programs to monitor the status of the environment more broadly face sizable scientific and logistical challenges related to what, where, and how often to measure. As a result, concerted efforts to integrate many kinds of ecological components across large geographic areas have been much rarer, despite recommendations by the National Research Council, the U.S. General Accounting Office, EPA's Science Advisory Board, and others beginning in the late 1970s.

In 1989, ORD responded to these recommendations by creating the Environmental Monitoring and Assessment Program (EMAP) to estimate the status and trends of the condition of the nation's ecological resources. The goals of this effort included evaluating the cumulative effect of programs designed to protect the environment and detecting emerging environmental problems before they became widespread or irreversible. During its early years, EMAP focused on developing scientifically sound "ecological indicators" (see chapter on Ecological Indicators for more information) and designs for monitoring major classes of natural resources at a national scale.

In 1995, ORD decided to pursue a major new direction for EMAP as a result of a review of national monitoring programs by a committee of federal agencies (the Committee on Environment and Natural Resources of the National Science and Technology Council). A component of the new approach, known as the Mid-Atlantic Integrated Assessment (MAIA), involves conducting intensive assessments of the environment on a regional scale as a model that can be transferred to other areas of the country. The Mid-Atlantic region of the United States was selected as the area to be studied for two reasons: first, the strong interest by both EPA Region 3 (the regional office that guides Agency activities in the Mid-Atlantic) and the Mid-Atlantic states; and second, the extensive environmental data already available for the region.

Approach of the Mid-Atlantic Integrated Assessment

The Mid-Atlantic region being assessed by MAIA encompasses the states of Pennsylvania, West Virginia, Maryland, Delaware, and Virginia (Figure 4-1), with adjacent portions of New York, New Jersey, and North Carolina also included in some assessments. The Mid-Atlantic contains a mosaic of ecological systems - lakes, streams, forests, agricultural areas, wetlands, and estuaries. It encompasses the Chesapeake Bay, the largest estuary in the world, and an uplands area that is among the most biologically diverse regions in the country. It is also home to over 35 million people and has experienced some of the most rapid population growth, industrial development, and intensive agriculture in the country. A wide range of environmental problems has accompanied this growth and development.

Beginning as a partnership between ORD and EPA Region 3 to assess these environmental problems, MAIA has grown to include other federal, state, tribal, and private environmental organizations. The overall goal of MAIA is to improve environmental decision making by incorporating the best available information on the condition of resources along with an improved understanding of the relative

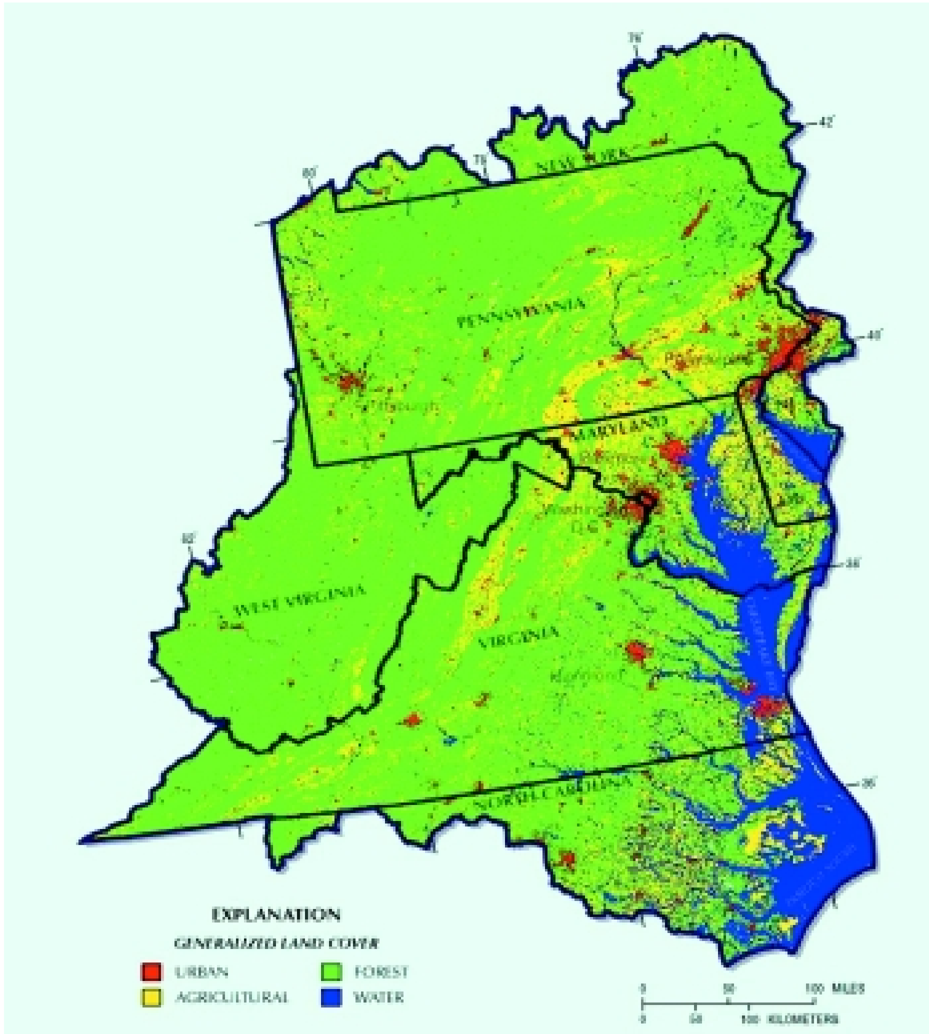


Figure 4-1. Land cover in the region being studied by MAIA.

impacts of various stressors and management actions. The major questions being asked by MAIA are the following:

- What are the environmental problems of concern?
- Where are they located?
- Are they getting better or worse?
- What is causing them?
- What can be done about them?

To answer these questions, ORD scientists and their partners have compiled vast amounts of information on the condition of ecological resources of the Mid-Atlantic from sources such as EMAP, the National Estuary Program, the Chesapeake Bay Program, state monitoring efforts, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Fish and Wildlife Service. The scientists have used this information to assess status and trends over a period of years to decades. They have also tested sampling designs and various ecological indicators to collect additional monitoring data about the status of the environment. Findings are being used to produce State-of-the-Region Reports, with contributions from many partners, that present resource-specific environmental data that can be understood by a broad spectrum of audiences. These reports will form the basis of an integrated regional “report card,” a concept proposed by Vice President Al Gore, being planned for 2002.

Recent Accomplishments

MAIA research has provided ***"proof of concept"*** for large-scale monitoring, emphasizing regional-scale rather than site-specific assessments. It sets a standard for integrating multiple environmental measures and for analyzing and presenting environmental data to the public. In 1998, MAIA completed its first two major MAIA products, ***An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas*** and ***Condition of the Mid-Atlantic Estuaries***. While both reports assess the Mid-Atlantic, the atlas focuses on conditions on land and the estuary report focuses on the waters that make up the region's extensive estuaries. These and other MAIA products are available through the MAIA website (www.epa.gov/maia).

The Landscape Atlas

The Landscape Atlas is a report that analyzes and interprets environmental conditions in 125 watersheds of the Mid-Atlantic, with a watershed consisting of an area of land drained by a single river or other body of water. It compares watersheds using 33 indicators of landscape condition, which were derived from satellite imagery and databases of features such as soils, elevation, and human population patterns. For some of the indicators, the Atlas compares watersheds in the Mid-Atlantic to watersheds in the other lower 48 states. An example of a landscape indicator used in the Atlas is the proportion of a watershed that has agriculture or urban land cover (with more land of this type considered less ecologically desirable) (Figure 4-2). The Atlas identifies patterns of land cover and land use across the region with respect to potential human impacts, water resources, forests, and landscape change. The level of detail and comparability seen in this report has never before been achieved across such a large area.

The report concludes that mountainous watersheds in the Mid-Atlantic contain the least amount of land in agricultural or urban use (and thus the greatest proportion of forests), while coastal areas have the lowest proportion of forests (Figure 4-3). Compared to many parts of the country, Mid-Atlantic watersheds have relatively favorable values for forest conditions, including forests along streams. An overall ranking based on factors such as population, road density, and amount of forests finds that the watersheds with the most desirable landscape conditions are in southern West Virginia and

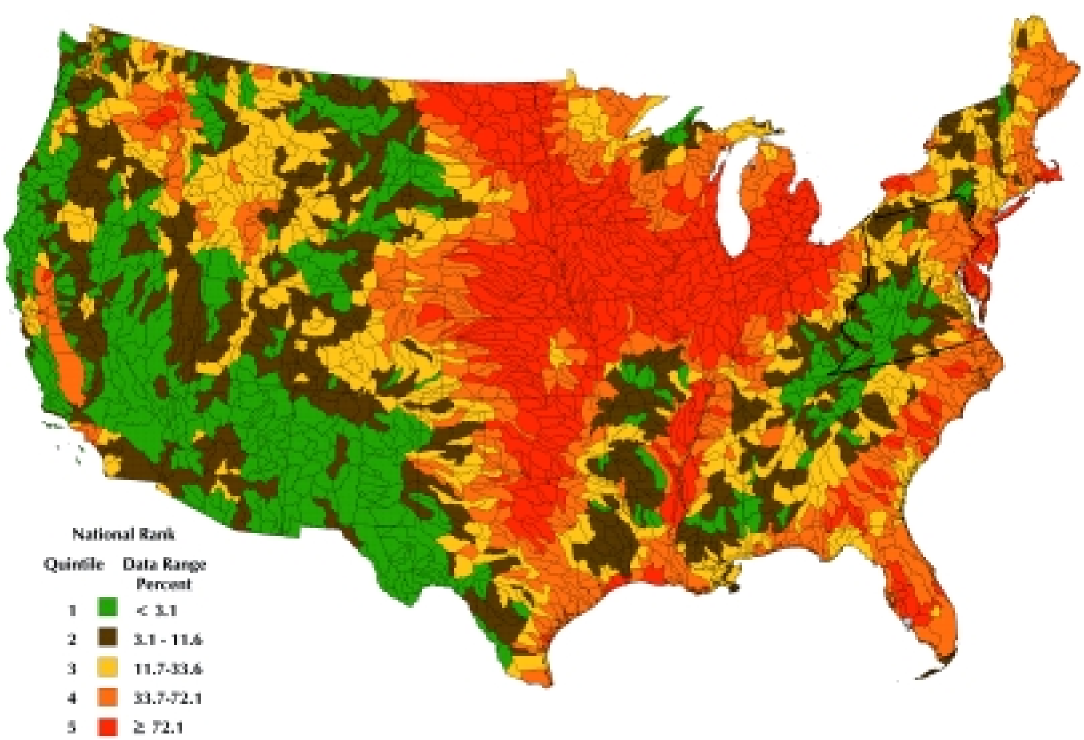


Figure 4-2. Proportion of watershed area with agriculture or urban land cover, from the Mid-Atlantic Landscape Atlas. In the atlas, each watershed is coded in one of five colors ranging from green (more desirable ecologically) to red (less desirable) for each condition that is evaluated. Each quintile (represented by one color) contains one-fifth of the watersheds.

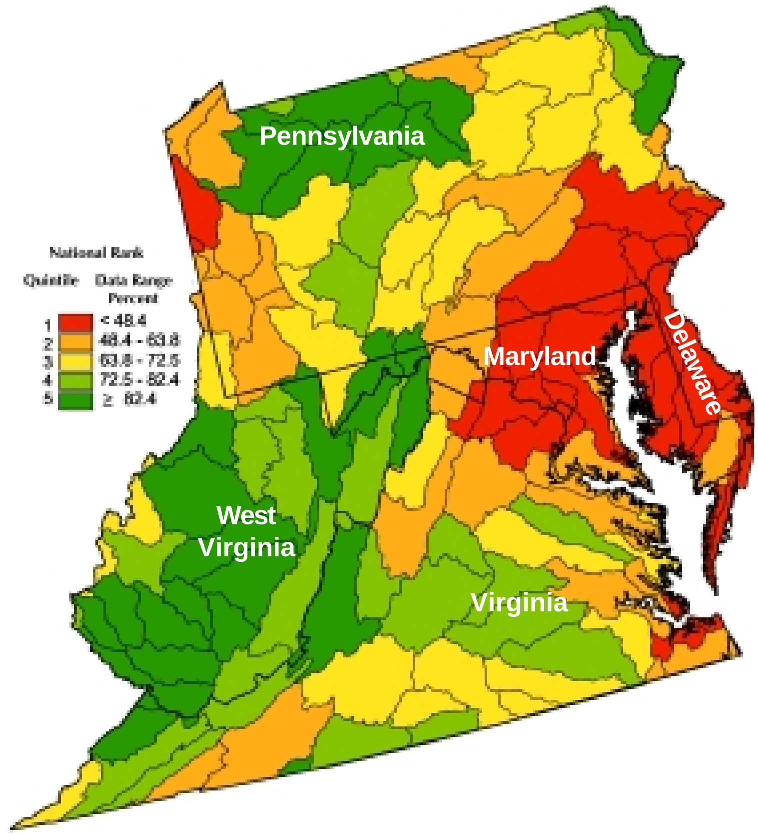


Figure 4-3. Proportion of watershed area that is forested in the Mid-Atlantic region, from the Mid-Atlantic Landscape Atlas. Watersheds with relatively low proportions of forests are clustered around major urban centers and Chesapeake Bay.

Virginia and in north-central Pennsylvania. Most of the watersheds with the least desirable conditions are clustered around the major metropolitan areas of Baltimore, MD, Washington, DC, Pittsburgh, PA, and Norfolk, VA.

The ecological snapshot provided by MAIA landscape work can be applied to current environmental and regional economic development decision making and will allow future trends in the region to be examined. For example, EPA is using MAIA land cover analyses in evaluating the potential impacts of a new, large-scale coal mining practice in the region that involves removing mountain tops and filling in valleys. Landscape analyses, along with other kinds of assessments, have indicated that mountain-top forests in areas proposed for mining are in relatively pristine condition and contain high quality streams. These findings are useful to EPA Region 3 in making regulatory decisions about mountain-top mining.

Condition of the Mid-Atlantic Estuaries

Estuaries are transitional zones where sea water mixes with fresh water flowing off the land. They provide habitats for many birds, mammals, fish and other aquatic life, and are important assets that people use in a variety of ways. The Delaware Estuary, Chesapeake Bay, and the coastal bays along the Delmarva (Delaware-Maryland-Virginia) Peninsula comprise the Mid-Atlantic estuaries and are the subject of a second major MAIA report, ***Condition of the Mid-Atlantic Estuaries***. This report synthesizes information gathered from various state and federal programs on the condition of the Mid-Atlantic estuaries from the early- to mid-1990s and describes how these estuaries have changed. The MAIA effort for estuaries reflects important scientific advances in large-scale assessment. Because of carefully designed programs to make sure sampling data were thorough and representative, conditions across all of the estuaries can be compared for the first time.

The report identifies the location of problem areas, and provides estimates of the percentage of estuaries in good, moderate, or poor condition based on specific environmental indicators. Indicators included water quality, sediment contamination, habitat change, and condition of living resources such as shellfish, fish, and waterfowl.

For example, the Chesapeake Bay suffers from over-enrichment with nutrients, which can lead to algal blooms and subsequent depletion of oxygen that threaten plant and animal life. As shown in Figure 4-4, about one third of Chesapeake Bay bottom waters are considered moderately or severely affected by low oxygen levels in the summer. Nutrient levels are declining, however, in response to measures such as improved wastewater management. The Delaware Estuary is impacted by the lack of water clarity and by toxic contaminants associated with urbanization and industrialization. The coastal bays are the least degraded estuaries in the Mid-Atlantic, but are threatened by encroaching urbanization. Across the region, oyster harvests have declined drastically over the past 100 years due to disease and other factors (Figure 4-5).

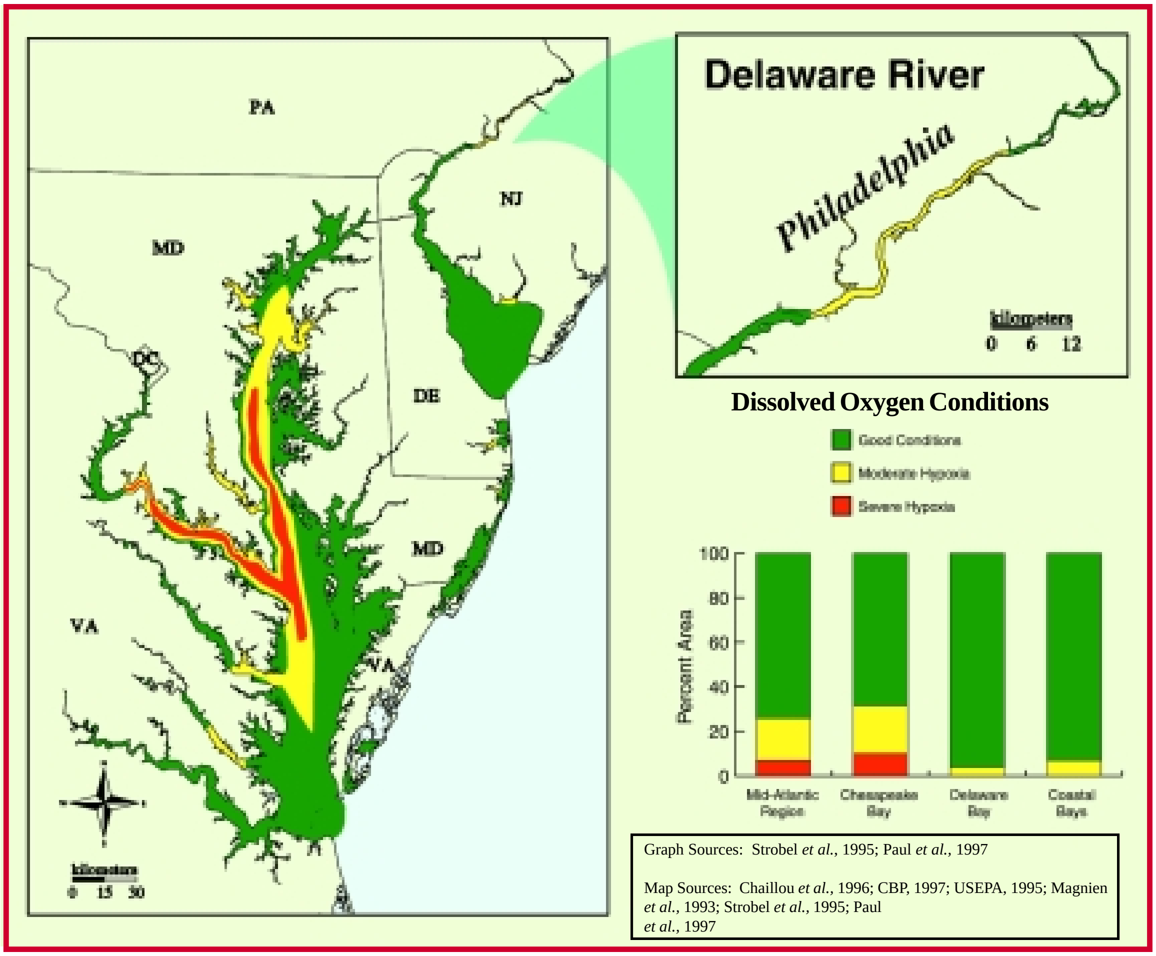


Figure 4-4. Distribution of summer-time dissolved oxygen within one meter of bottom sediments across estuaries in the Mid-Atlantic region, from *Condition of the Mid-Atlantic Estuaries*. Conditions of low levels of dissolved oxygen (hypoxia) can harm bottom-dwelling organisms and are most widespread in the middle portions of the Chesapeake Bay and the lower Potomac River.

The report is proving useful to environmental managers. For example, Maryland has established a National Estuary Program to further protect Maryland's coastal bays based on the report's findings.

Where Do We Go From Here?

MAIA efforts are proceeding on several fronts. First, MAIA participants have built upon the work of the estuaries report by developing a comprehensive, integrated monitoring design that consists of more than 700 stations throughout the Mid-Atlantic estuaries. For the first time, a common set of key indicators of overall environmental quality are being adopted by the various state and federal organizations studying these estuaries. A number of other "State of the Region" MAIA reports are also underway, including reports on streams, groundwater, forests, and agricultural lands.

MAIA is also beginning to develop methods to integrate the individual resource assessments prepared for the State of the Region reports. One effort focuses on the use of ecological indicators that provide information across multiple categories of resources. Two promising examples are indicators based on monitoring of bird and amphibian populations. MAIA is also exploring ways to connect indicators of environmental condition with assessment of public health. The goal is to prepare integrated assessments that bring together information about ecological and human health effects, social goals, economics, politics, and law in a way that is useful to policy makers. Such efforts will be complemented by MAIA efforts to develop cost-effective and reliable approaches for managing or restoring ecosystem components, such as habitats along streams and rivers (riparian zones).

Additionally, MAIA plans to move from assessing current environmental conditions to predicting

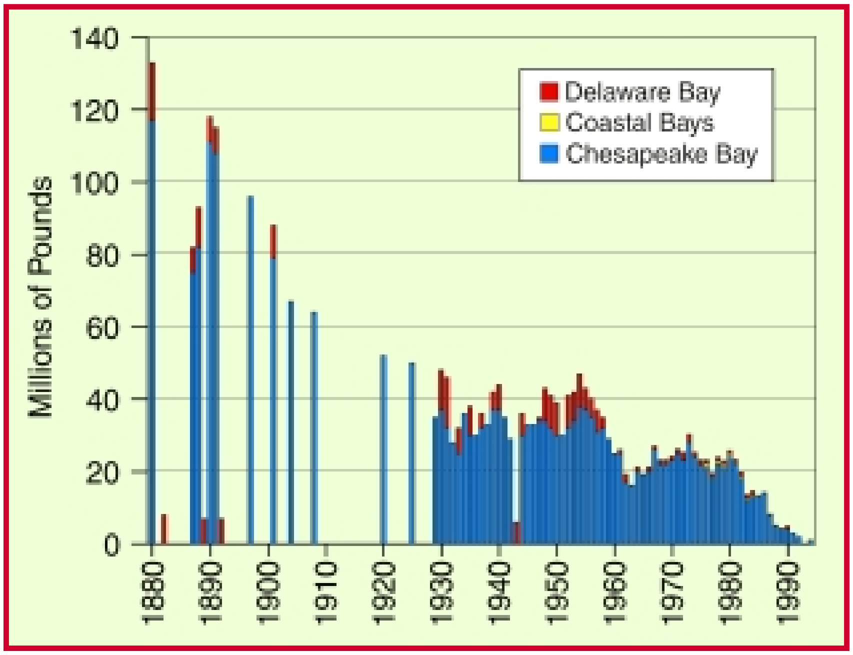


Figure 4-5. Annual oyster harvest for Mid-Atlantic estuaries, from *Condition of the Mid-Atlantic Estuaries.* Gaps in the late 1800s and early 1900s represent missing data. Harvests have plummeted due to disease, pollution, and over-harvesting.

future conditions. ORD's Regional Vulnerability Assessment (ReVA), which, like EMAP, will initially focus on the Mid-Atlantic, will be a major component of this effort. ReVA will develop the next generation of measurements and tools to assess the simultaneous impact of stressors such as urbanization, industrial and agricultural pollution, and climate change to make regional predictions of environmental conditions over the next five to 25 years. This will improve the ability of decision makers to evaluate the consequences of various economic, land use, and environmental choices before they are made. The first phase of ReVA is the *Mid-Atlantic Stressor Atlas*, currently in draft, which looks at stressors such as mining, agro-chemicals, ground level ozone, and land use change.

In its short existence, MAIA has forged alliances among federal and state agencies to cooperatively answer questions about the condition of the environment and whether it is improving or declining. The success of the program has prompted ORD to begin a new intensive regional assessment, this one for the western United States (Figure 4-6). The EMAP Western Pilot will test the approach used by MAIA on a much larger scale in a region that contains ecosystems not present in the Mid-Atlantic, such as mountainous and arid zones. The Western Pilot is planned to be a five-year cooperative effort between EPA, the states, and tribal nations concentrating on estuaries, inland waters (e.g., streams), and landscape characteristics. The program will assess problems of critical importance to resource managers and environmental decision makers throughout this region. Together, MAIA, ReVA, and the EMAP Western Pilot are advancing the scientific basis for evaluating the condition of the environment in ways that can be applied throughout the United States.

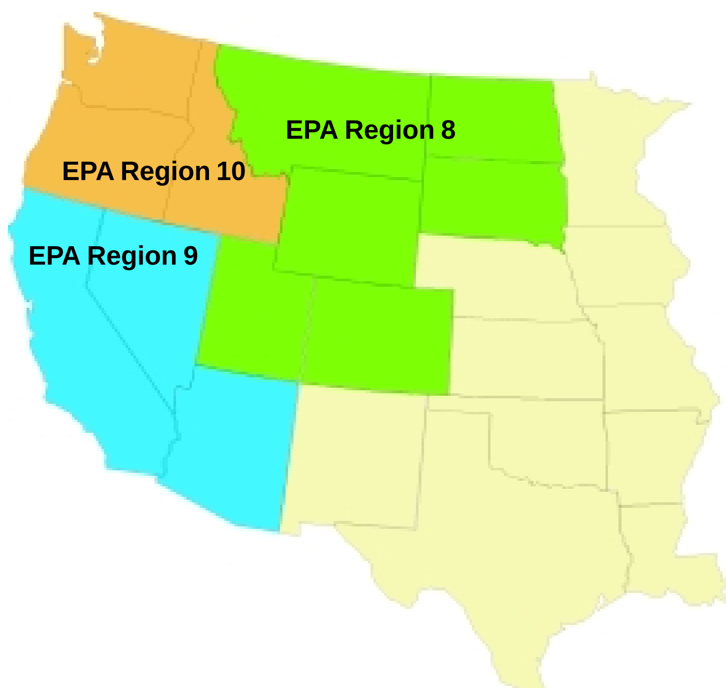


Figure 4-6. The geographic scope of the EMAP Western Pilot.

5. Endocrine Disruptors

In the 1950s, scientists became concerned by dramatic declines in the reproductive success in bird populations, which were experiencing problems such as hatching failures due to eggshell thinning. These effects were found to be caused by exposure to a class of pesticides known as organochlorine pesticides, particularly DDT. Scientist Rachel Carson opened the eyes of the American public to these and other effects of pesticide use with her 1962 book *Silent Spring*. In the 1970s, doctors traced reproductive tract cancers in women to DES, a drug similar to the hormone estrogen, which was used by their mothers in the 1950s to prevent miscarriage. Although these two events may outwardly appear dissimilar and unrelated, they both are cases of chemicals interfering with the functioning of the endocrine (hormone) system. Over time, scientists began piecing together this and other evidence of adverse effects in wildlife and humans to develop a hypothesis that chemicals could be causing widespread harm by disrupting the endocrine system.

The endocrine system plays a key role in the development, growth, reproduction, and behavior of humans and wildlife. Endocrine glands (Figure 5-1) produce hormones that act as chemical messengers, traveling through blood to tissues and organs where they can bind to specific cell sites called receptors. By binding to receptors, hormones trigger numerous responses, such as the release of eggs from ovaries. Hormones are tightly regulated by the body, and exposure to chemicals that alter their function may result in abnormal growth and development. The consequences of hormonal disruption during an animal's development can be profound and long-lasting, and developing organisms are therefore especially at risk. Chemicals that interfere with any aspect of hormone production, activity, or elimination in the endocrine system are referred to as endocrine disrupting chemicals (EDCs). They are also sometimes referred to as *hormonally-active agents*. Suspected EDCs include chemicals among the following classes of compounds: pesticides; polyhalogenated aromatic hydrocarbons; plasticizers; industrial surfactants; pharmaceutical agents; and substances naturally found in some plants (phytoestrogens).

Potential Effects on Wildlife and Humans

Evidence of potential effects from EDCs has been collected primarily through laboratory animal experiments and documentation of effects in wildlife in specific contaminated ecosystems such as the Great Lakes. To date, problems have predominantly been identified in wildlife species with relatively high exposures to specific compounds (e.g., DDT, PCBs, and dioxins), or in domestic animals consuming plants with high levels of phytoestrogens.

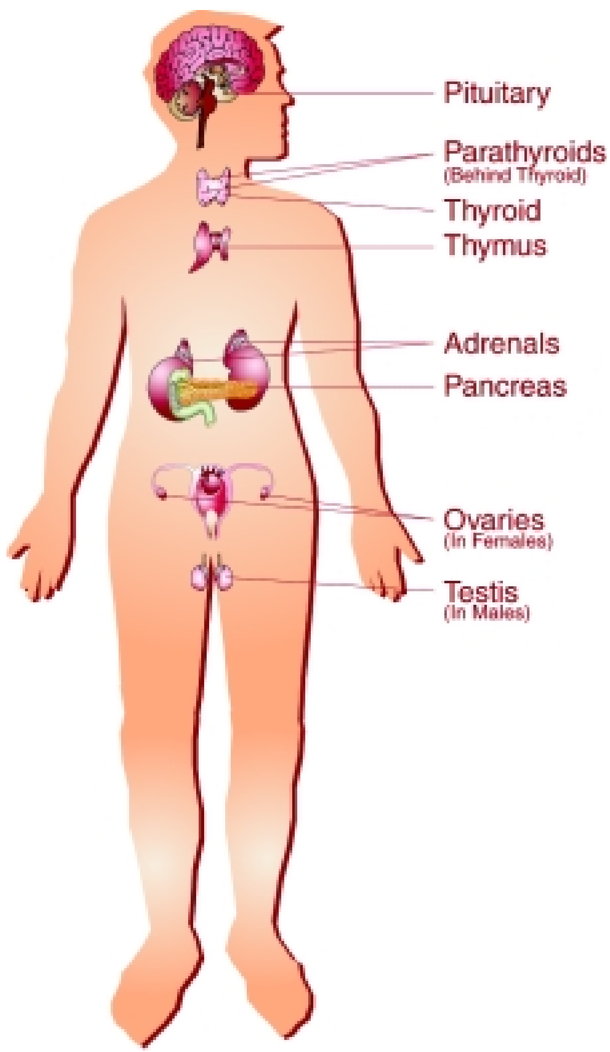


Figure 5-1. The human endocrine system.

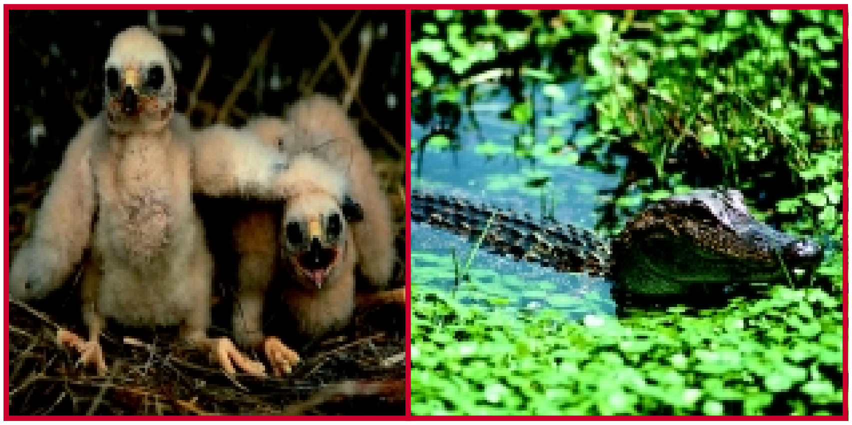


Figure 5-2. Chemical contamination has been found to interfere with reproductive functioning in a number of wildlife species. Populations of several species of raptors (left) dropped precipitously before DDT was banned in the United States. Alligators (right) developed abnormal reproductive organs following pesticide spills that reached Lake Apopka, Florida.

Examples of effects on wildlife potentially due to EDCs (Figure 5-2) include the following:

- Birth defects in a Lake Michigan bird population (cormorants) exposed to PCBs and other compounds.
- Nearly complete mortality of young Lake Ontario lake trout, presumably resulting from exposure to dioxin-like compounds.
- Abnormal reproductive development in alligators in Lake Apopka, Florida, following a pesticide spill.
- Simultaneous presence of both male and female reproductive organs (imposex) in mollusks exposed to chemicals (alkyltins) used to prevent the growth of organisms such as barnacles and algae on ship hulls.
- Synthesis in male fish living near sewage outfalls of a hormonally-regulated protein (vitellogenin) normally found only in female fish.

In humans, in addition to the well-documented effects of DES, studies have indicated that PCBs and related chemicals may cause developmental neurological problems in exposed children. Furthermore, scientists have speculated that EDCs could be responsible for such effects as reported declines in the quality and quantity of sperm production over the last four decades and increases in certain cancers (breast, prostate, testicular) that may have an endocrine-related basis.

Despite documented cases of endocrine disruption, the scientific community has not reached a consensus on the extent of the problem. Information about how, at the cellular level, apparent EDCs are causing their effects is almost always lacking. Knowledge about the effects of EDCs at low doses and the levels at which exposure to EDCs occurs is limited. To answer the many questions surrounding the endocrine disruption hypothesis, concerted research programs are needed. ORD is contributing to this research. To understand ORD's role, it is helpful to understand the context of national and international research and recent legislative developments affecting EPA.

A Coordinated Federal Program

Given EPA's mandate to protect both public health and the environment, the Agency has for several years taken a leadership role in investigating endocrine disruption. Other federal agencies are involved as well. To coordinate research across the federal government, the Committee on Environment and Natural Resources (CENR) of the National Science and Technology Council (NSTC) convened an endocrine disruptor Working Group, chaired by EPA, in 1996. The NSTC advises the President and federal agencies on directions for national research and development efforts. The Working Group developed an inventory of federal research programs, identified high priority research gaps in the federal portfolio, and developed a national research framework (www.epa.gov/endocrine). These efforts have helped both ensure cooperation on endocrine disruption research within the federal government and refine the research areas on which EPA is concentrating.

An Environmental Issue That Transcends National Boundaries

Many suspected EDCs are long-lived and mobile in the environment, meaning they can readily be transported across national boundaries. This has contributed to shared international concern about their impacts. Additionally, the breadth of the scientific uncertainties about the causes, effects, and solutions for this issue necessitate international cooperation and communication. The international community has responded on both the research and the policy fronts. Internationally, at least 25 major scientific workshops have been held over the past five years to assess the scope and magnitude of the potential EDC problem, most of which have involved ORD participation. Nations have also begun

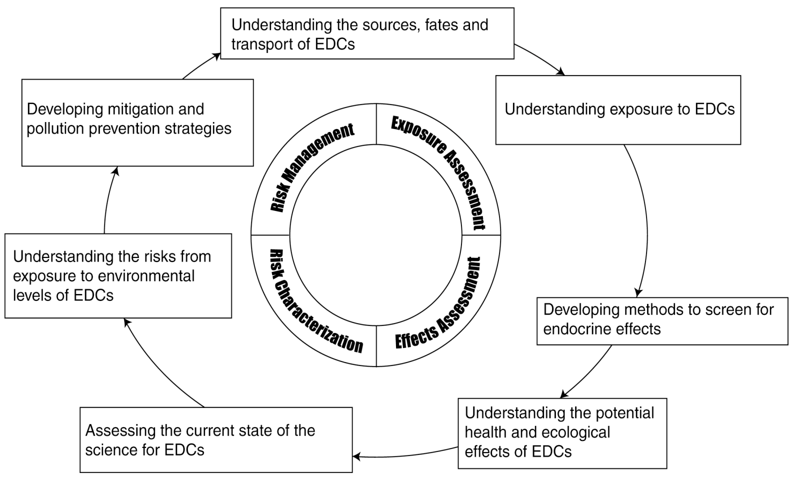


Figure 5-3. Some of the major research and assessment activities conducted by ORD in examining potential disruption of the endocrine system in humans and wildlife due to environmental contaminants.

international initiatives such as developing screening and testing guidelines for EDCs through the Organization of Economic Cooperation and Development (OECD) and other international venues.

Legislation

Concerns about endocrine disruption in the environment have impacted national legislation as well. In 1996, the Safe Drinking Water Act Amendments and Food Quality Protection Act (FQPA) were enacted. Aspects of these two laws mandate the development of a screening and testing program to evaluate the potential of chemicals found in drinking water and food to have hormonal activity. ORD supports EPA's Office of Water and Office of Prevention, Pesticides, and Toxic Substances in meeting the requirements of these laws. EPA is developing an Endocrine Disruptors Screening and Testing Program (EDSTP), taking into consideration recommendations received from an advisory committee in which ORD was an active member. The scientific questions that must be answered to create a successful testing program have placed additional demands on ORD research.

ORD's Research Program to Answer Outstanding Scientific Questions

Based upon recognition of the potential scope of the problem, the possibility of serious effects on the health of populations, and the persistence of some endocrine-disrupting agents in the environment, ORD identified research on endocrine disruption as one of the six high-priority topics in its 1996 Strategic Plan. In 1998, ORD published an endocrine disruption research plan (www.epa/gov/ORD/WebPubs/final/) that presented ORD's research priorities for this topic. ORD research reflects the national and international efforts to prioritize research needs and the legislative mandates described previously. As described in the Introduction, ORD uses the risk assessment/risk management framework to organize its research approach in solving scientific and technological problems. This framework is visually portrayed in the inner ring in Figure 5-3, with ORD's major endocrine disruption activities depicted by the outer ring. Major uncertainties exist in virtually every aspect of assessing the impact of endocrine disruption. Key questions for ORD identified in the research plan include the following:

- **Health and ecological effects:** What effects are occurring in exposed human and wildlife populations? What are the chemical classes of interest? What are the potencies of these chemicals at low doses? Do testing guidelines adequately evaluate potential endocrine effects? How can experimental findings be extrapolated from one system to another, such as from tissue cultures to whole organisms? What are the effects of exposure to multiple EDCs?
- **Exposure:** How and to what degree are human and wildlife populations exposed to EDCs? What are the major sources and environmental fates of EDCs?
- **Risk management**: How can unreasonable risks be managed? Are new technologies needed?

Recent Accomplishments

Assessing the Current State of the Science

In 1997, EPA's Risk Assessment Forum published a report entitled *Special Report on Environmental Endocrine Disruption: An Effects Assessment and Analysis* (www.epa.gov/ORD/WebPubs/endocrine/). The Risk Assessment Forum is staffed by ORD and brings together expert panels from across EPA. The report assessed the current state of the science for endocrine disruption in humans and wildlife. For human health, the report concluded that with few exceptions (e.g., DES, PCBs), a causal relationship has not been established between exposure to a specific chemical and an endocrine-mediated adverse effect. For ecological effects, the report noted that although a number of compounds can affect development in invertebrates, fish, and wildlife via the endocrine system, few examples established the extent to which these effects have had impacts on populations of organisms.

This report was significant for a number of reasons. First, it represented a cross-Agency assessment of the state of the science. Second, it resulted in the development of an interim Agency position on EDCs that has served to guide Agency decisions since. Third, its release allowed the scientific and regulated communities to know EPA's position on EDCs. The conclusions of EPA's report have since been largely supported by the endocrine disruption report of the National Academy of Sciences, released in August 1999.

Developing Methods to Screen for Endocrine Effects

Literally thousands of different chemicals can be found in commerce, most of which have never been tested for their effects on the endocrine system. The 1996 Food Quality Protection Act (FQPA) recognized this by requiring EPA to develop a screening and testing program for endocrine disruptors. At the time the law passed, a standardized and validated battery of tests for endocrine disruption did not exist, and ORD is playing a critical role in helping develop needed assays in support of EPA program offices. These screening assays will be used to determine whether more in-depth, long-term test procedures are needed to characterize potential risks to the endocrine system.

Because of concerns of potential adverse effects to fish populations from EDCs, EPA has decided to include within the battery of endocrine tests a hormonal screening assay involving fish reproduction. ORD scientists have completed the initial stages in developing such a screening test using fathead minnows (Figure 5-4). In developing this test, investigators designed techniques to measure baseline or "normal" values of sex hormones (estrogen and androgen) and vitellogenin (a protein found in egg yolk that is regulated by estrogen) that guide reproduction in this species. The assay allows scientists to compare values obtained following exposure to chemicals with unknown effects with baseline values to see if the chemicals may be impacting the endocrine system. Further work is focusing on standardizing the procedures for this 21-day reproductive function assay.

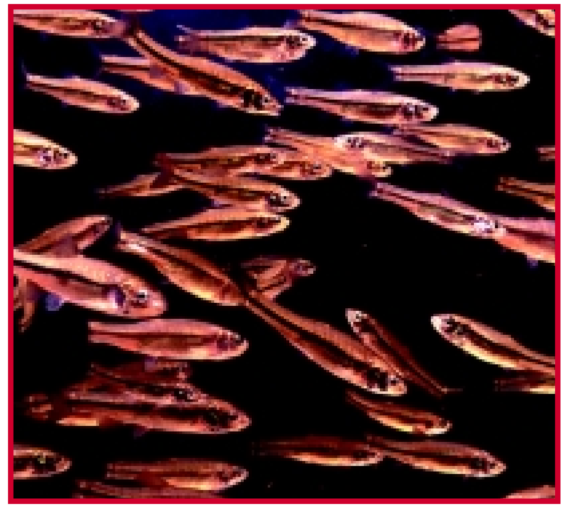


Figure 5-4. Using the fathead minnow, ORD has developed a screen for potential adverse effects to fish from hormonal effects of chemicals.

Given that testing the thousands of chemicals for which little endocrine data exist could take substantial funds and time, ways to prioritize the testing are needed. ORD researchers made promising progress in an approach to prioritizing testing by making inferences about a compound's potential effects based on its chemical structure. These inferences draw upon what are known as quantitative structure activity relationships (QSARs). ORD researchers contributed PC-based modeling techniques for predicting the ability of a chemical to bind to receptors for estrogen and androgens, which could indicate potential for disrupting endocrine functions that involve these sex hormones. It is hoped that when these techniques are fully validated, they will be used to rapidly prioritize chemical databases for testing.

Understanding the Potential Health and Ecological Effects of EDCs

Given the many uncertainties regarding the potential health effects of EDCs in humans and wildlife, most of ORD's research program has been focused on addressing these data gaps. The research efforts have covered a broad set of hormones and their pathways, in a variety of species, that may be disrupted by numerous environmental pollutants.

One aspect of endocrine functioning that ORD has studied involves the thyroid gland. ORD found that in laboratory rats, exposure to PCBs depressed thyroid hormones during a critical period of

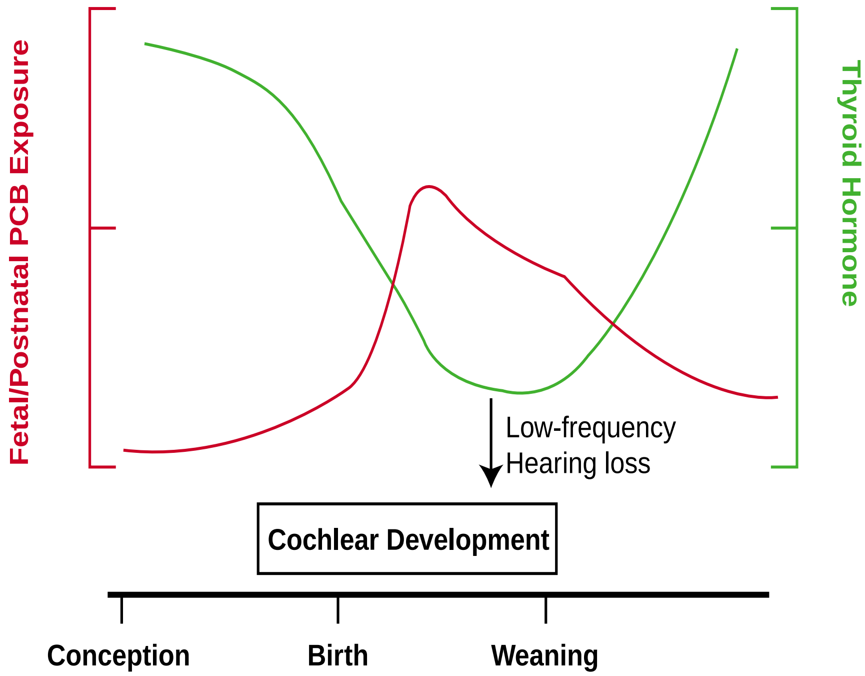


Figure 5-5. Model of hearing loss caused by PCBs due to endocrine disruption. If female rodents are exposed to PCBs, their progeny also may be exposed to PCBs via the placenta before birth and mother's milk after birth. Rising PCB levels (red line) can depress thyroid hormone levels (green line), causing the cochlea (inner ear) to develop abnormally. The result is difficulty in hearing low-frequency sounds.

development of the inner ear (cochlea), preventing development of the outer hair cells and resulting in hearing loss (see Figure 5-5). The hearing loss could be prevented by administering thyroxine (a thyroid hormone) at the same time as PCBs, which supported the conclusion that the effect was caused by disruption of normal thyroid functioning. This research provided the first evidence from an animal model of a structural defect in the nervous system following exposure to PCBs during development. It also highlighted the need for additional studies on how changes in thyroid function affect the developing nervous system.

ORD is also studying disruption of reproductive hormones, which can result in abnormal reproductive organs or abnormal reproductive function if it occurs during critical periods of development. For many years, ORD researchers have been studying the potential of environmental chemicals to interfere with the function of testosterone, an androgen (male sex hormone). Previous ORD research had demonstrated that, in laboratory animals, a metabolite of DDT (p,p'-DDE) can act as an "anti-androgen" by blocking testosterone from binding to its receptors. Recently, ORD scientists have further discovered that other environmental chemicals such as some fungicides (e.g., vinclozolin), herbicides (e.g., linuron), and plasticizers (e.g., some phthalates) also act as anti-androgens and when administered late in pregnancy caused severe malformation of male reproductive organs in laboratory animals. Findings such as these have led EPA to decide to screen chemicals for their potential to act as anti-androgens under the screening and testing program mandated by FQPA. Figure 5-6 shows the chemical structure of testosterone and several chemicals found to block its receptor binding.

ORD scientists have also studied a hormonal system critical for normal development known as the retinoic signaling pathway. In recent years, limb malformations have been observed in a variety of North American frogs and other amphibians. One of several hypotheses under study by ORD and others is that the malformations are the result of disruption of the retinoic acid signaling pathway. ORD scientists exposed leopard frogs to methoprene, a chemical used to control mosquitoes and other insects that has been reported to interfere with this pathway. Although the investigators did not find evidence that methoprene causes amphibian malformations similar to those observed in the field, very high concentrations did cause lethal developmental abnormalities (Figure 5-7). This research is contributing to an understanding of the possible causes of the malformations as well as extending the study of endocrine disruption beyond the set of hormones that have been most studied to date.

Understanding Exposures to EDCs

To accurately assess the degree of exposure to EDCs – a necessary step in assessing their risks – tools must be available to measure them in the environment, in some cases at extremely low levels (e.g., parts per trillion and below). ORD scientists have determined that for some suspected EDCs, analytical tools either are not available for measuring them or are not

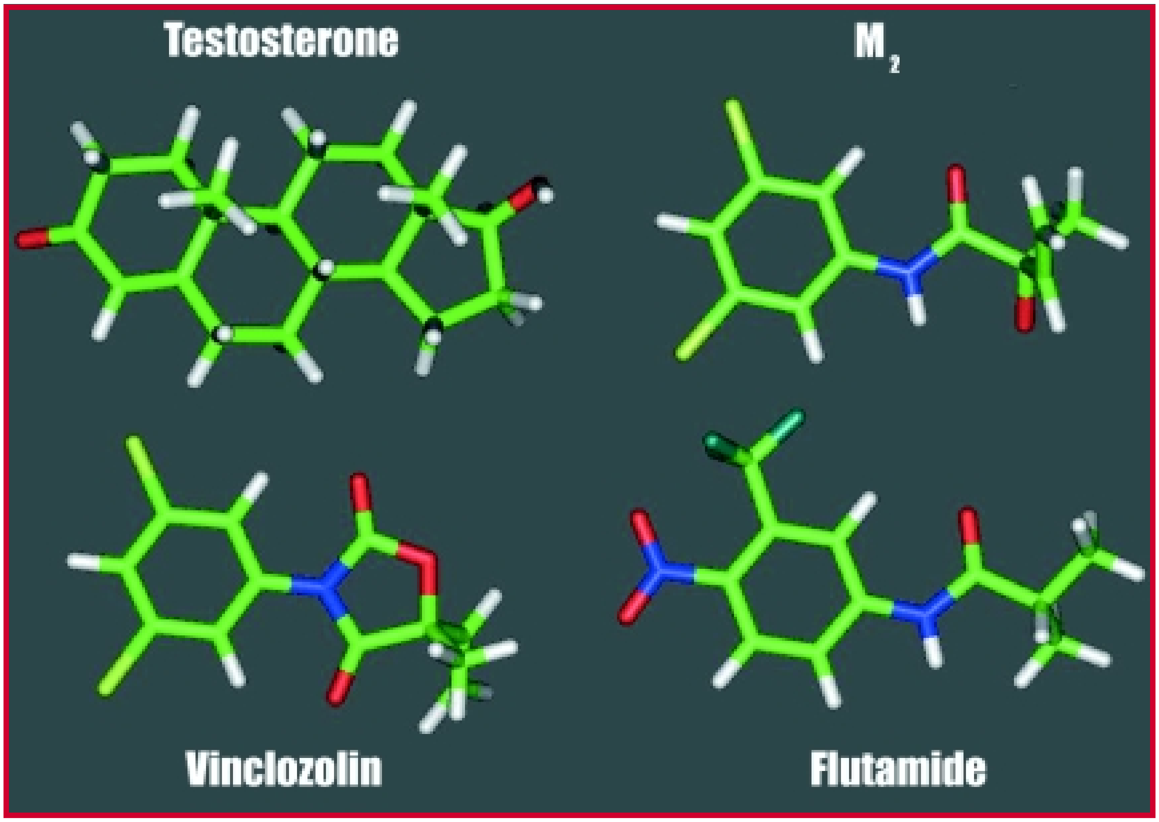


Figure 5-6. Testosterone and anti-androgens. The top left structure depicts testosterone, a natural male hormone (androgen). The bottom right structure depicts a pharmaceutical drug, flutamide, considered an anti-androgen because it binds to the same receptors as testosterone, thereby interfering with its functioning. The fungicide vinclozolin (bottom left) is not a direct anti-androgen, but it breaks down into M_2 (top right), which like flutamide, is anti-androgenic.

sensitive enough to detect them in water, soil, and other environmental media. Therefore, a major focus of ORD's exposure program has been the development of analytical methods for determining the extent of EDCs in the environment. Once these tools are developed, ORD scientists publish their findings in the peer-reviewed literature so other scientists can use them.

During 1997 to 1998, ORD chemists developed or improved analytical tools for measuring a number of suspected EDCs, including organochlorines, PCBs, and polycyclic aromatic hydrocarbons (PAHs). ORD scientists then tested these tools in the Neuse River Basin of North Carolina (Figure 5-8) as part of a broader effort to develop a risk assessment of EDCs within this area. ORD scientists also tested a variety of screening tools, such as commercially available immunoassay kits, in the basin. The U.S Geological Survey, Duke University, North Carolina State University, the University of North Carolina, and others collaborated with ORD in this work. Suspected EDCs were analyzed in water, soil, sediment, fish, and other selected plants and animals at a low impact agriculture area, two high impact agriculture sites, and a coastal site. Examples of analytical tools developed and tested through this effort were gas chromatography-mass spectrometry (GC-MS) methods for detecting suspected EDCs at low levels in white-tailed deer, fish tissue, natural waters, and sediments. ORD chemists also developed

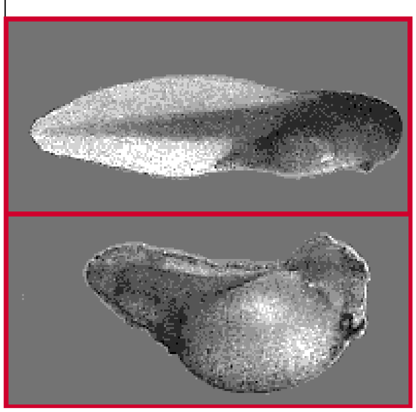


Figure 5-7. The effects of methoprene on leopard frog tadpoles (*Rana pipiens*) at day six of development. The top panel depicts normal development in a control organism. The bottom panel shows the typical effects of methoprene on development. High levels of methoprene exposure (458 ppb) resulted in complete mortality.

a high performance liquid chromatography (HPLC) method for measuring different isomers (forms) of PCBs in fish. Finally, ORD scientists designed and tested a DNA-probe to screen for exposure of fish to EDCs. The probe takes advantage of the fact that hormonally-active contaminants can switch on certain genes in fish tissue, which are then detectable.

ORD used the results from the application of the analytical tools to samples collected in the Neuse to develop a computer model simulating the movement of a suspected EDC, benzo-a-pyrene, through the Middle Neuse Basin. Known as MEND-TOX, the model predicts the movement of this compound through different compartments of the environment, such as water, sediment, and fish tissue. With future data, this multi-media compartmental model will be expanded and tested with other EDCs. When fully developed, it will be a useful tool for assessing possible exposure in other ecologically similar river basins.

Demonstrating Leadership Nationally and Internationally

As described in the introduction to this chapter, EPA is leading an interagency Working Group, under the auspices of the CENR, to coordinate endocrine disruption research activities of the federal government. As part of these efforts, ORD led the 1998 revisions to the inventory of EDC projects funded by the federal government that ORD originally created in 1996. The inventory is an Internet-accessible database (available at www.epa.gov/endocrine) that can be searched by topics such as chemical, species, or hormonal effect. The 1998 update added projects from Canada, Japan, and Europe to the U.S. component, bringing the inventory to more than 700 projects. The inventory has been used by the CENR Working Group to assess how well the critical research needs it identified were being addressed by government research and to develop a multi-agency grants program to fill the biggest gaps.

Where Do We Go From Here?

The results of the EDCs research program highlighted in this report are providing valuable insights into understanding the potential effects of EDCs and their patterns of exposure for humans and wildlife. Following the risk assessment/risk management framework depicted in Figure 5-3, ORD continues to focus on the most critical uncertainties in determining whether humans and wildlife populations are being impacted by levels of endocrine disruptors in the environment and in identifying the sources of those exposures. As these issues become further resolved, ORD will place greater attention on the development of an

Figure 5-8. The Neuse River Basin of North Carolina has been the focus of ORD studies on how to measure environmental concentrations of chemicals that may disrupt the endocrine system. Map prepared by the North Carolina Center for Geographic Information & Analysis.

integrated risk assessment framework for endocrine disruption and mitigation strategies to reduce risks. ORD also will continue to lead national and international efforts to coordinate endocrine disruption research programs.

ORD is committed to continued support for the development of methods and their standardization and validation for the screening assays required by the Food Quality Protection Act. Particular attention will be focused on refining the mammalian tests for estrogen, androgen and thyroid action, and in developing and standardizing the amphibian and fish bioassays. ORD will continue to refine and validate the fish bioassay and PC-based modeling techniques described above. These efforts are being organized under an interagency Endocrine Disruptor Screening Program Taskforce that is also working to standardize test methods internationally in conjunction with the OECD. The goal of the screening programs is to efficiently identify chemicals that may pose risks because of their effects on the endocrine system.

ORD also plans a number of projects to investigate the potential health and ecological effects of EDCs. For example, ORD will study the effects of atrazine on the endocrine system to help determine how this herbicide causes mammary tumors in rats. ORD will also examine the impact of phthalate esters on the development of the male reproductive tract in light of observations that some of these plasticizers can act as anti-androgens. Another important research area will compare endocrine disruption in different kinds of animals so that results observed in one class of animals can be more readily applied to other classes.

In the area of exposure assessment, ORD will continue laboratory and field research to develop and verify techniques for measuring EDC concentrations and exposures in the environment. The Neuse River Basin of North Carolina will remain a focal point of the research, with efforts expanded to include broader classes of chemicals and wider coverage of the environment. ORD will also continue to develop and refine models of the movement of EDCs through the environment and the resulting exposures experienced by people.

ORD is working with organizations such as the National Institute of Environmental Health Sciences (NIEHS) to identify the critical risk assessment issues for EDCs. EDC risk assessment remains a challenge because effects may be a consequence of the cumulative impact of a wide range of contaminants that act in similar ways. Moreover, exposure to substances other than contaminants, such as compounds naturally found in some plants, may confound interpretation of the endocrine effects of contaminants. A case study involving integration of human and ecological assessments for classes of EDCs will be prepared as a central component of this effort.

In the area of risk management, ORD is pursuing efforts in several areas. One area is preventing or controlling the release of suspected EDCs into the environment, such as alkylphenols from sewage treatment systems, airborne dioxins from industrial sources, and other EDCs in chemical production plants. ORD is also developing and evaluating tools for destroying or containing EDCs in soils at Superfund sites or in contaminated sediments.

Finally, in an effort to engage the best scientists in the academic community in addressing the scientific uncertainties regarding EDCs, ORD has carried out a STAR grants effort devoted to endocrine disruption since 1996. ORD has awarded grants across several areas of the risk assessment paradigm, such as developing methods to monitor and model exposures, developing biomarkers of exposure and effects, constructing short term screening assays, studying the effects of endocrine disruptors in wildlife populations, and investigating human health endpoints that may be related to endocrine disruption. In 1998, ORD linked its STAR grants program with a broader interagency set of grants for endocrine disruption issued under the umbrella of the CENR and currently continues to participate in this partnership.

6. Environmental Risks to Children

To young children, the world is full of objects to be grabbed, tasted, and chewed – edible or not. As they explore their surroundings, children gain valuable skills, but they also come into contact with chemicals found in or on carpets, toys, furniture, lawns, and many other items. These activities can lead to greater exposure to chemicals than adults who share the same environment. Because their bodies process chemicals differently than adults and they experience windows of vulnerability as their bodies develop, children can also be more sensitive to toxic effects. For example, mercury and lead appear to harm the developing nervous systems of children at levels that do not harm adults. Infants and young children also eat different types of food and consume more food and fluids per unit of body weight than adults.

These differences between children and adults have gained heightened attention over the past decade. In 1993, the National Academy of Sciences published a report entitled *Pesticides in the Diets of Infants and Children*. In 1995, EPA announced a policy to explicitly consider children when assessing environmental risks. The Food Quality Protection Act of 1996 and the Safe Drinking Water Act Amendments of 1996 also require EPA to give special attention to children. In 1997, the President signed an Executive Order directing federal agencies to give a high priority to protecting children from environmental health and safety risks.

In implementing these directives, EPA has realized that scientific knowledge is not yet sufficiently advanced to accurately assess environmental risks to children. In response, ORD is carrying out a research program to fill in gaps in understanding about how children are exposed to environmental contaminants, what health effects these contaminants might cause, how to assess risks to children, and how to prevent or reduce exposure to these contaminants. The research also involves studying known health problems of children, such as asthma, to see what role environmental exposures may play (Figure 6-1).

Recent Accomplishments

Exposure of Children to Environmental Contaminants

Though most people think of pollution as existing outdoors, much of children's exposure to chemicals actually occurs indoors. Children spend most of their time indoors, where chemicals can be released (e.g., from consumer products or building materials) or infiltrate the home from outdoors. Chemicals can also be tracked-in with contaminated soil or brought inside on workplace clothing. ORD is studying how children are exposed to potentially harmful chemicals that occur indoors and are slow to degrade. Pilot studies completed by ORD scientists in 1997 evaluated the exposure of children to contaminants in their homes and nine day care centers in the Durham, North Carolina area. The chemicals studied included PCBs, polycyclic aromatic hydrocarbons (PAHs), phenols, and various pesticides. The studies found that for some chemicals, children received most of their exposure through the air, while for others most exposure occurred through the diet. Generally, differences in exposure among the day care centers and the homes were small.

Figure 6-1. ORD is investigating the environmental risks faced by children.

Health Effects of Environmental Contaminants

In the field of toxicology, ORD is studying the effects of chemicals on young animals both before and after birth. Findings on how young animals are affected can be used along with exposure information to predict whether children may face similar risks and, ultimately, in deciding whether additional steps to protect children's health are needed. For example, ORD toxicologists have studied chlorpyrifos, a pesticide widely used to control insects. They found that young laboratory rats were five to seven times more sensitive to nervous system effects than adult rats. Subsequent studies found that enzymes produced by the body to detoxify the pesticide were not as effective in young animals as adults, resulting in the greater sensitivity observed. Other research found that if pregnant rats were exposed to the pesticide, fetuses could be exposed as well. The development of the visual system also appears to be affected by chlorpyrifos early in life, based on experiments using birds, which are more similar to humans than are rodents in the structure and development of their eyes.

Other studies by ORD toxicologists found that the developing fetus is at special risk to the adverse effects of dioxin and related chemicals. Exposing rodents to dioxin prior to birth (prenatally) caused permanent alterations in the developing reproductive tract of both female and male offspring. Not only can these alterations affect future reproduction, but they might lead to enhanced susceptibility to cancer of the reproductive organs. Many of the effects are not detectable until puberty or even later in life. Another study found that prenatal exposure to dioxin resulted in long-term suppression of one form of immune response (delayed-type hypersensitivity) important in defending against certain bacterial and viral infections.

Reducing Exposure to Environmental Contaminants

ORD scientists collaborated with the Robert Wood Johnson Medical School and the Centers for Disease Control and Prevention (CDC) to conduct the Children's Lead Exposure and Reduction Study. If children are exposed to excessive levels of lead from ingestion of lead paint dust (or other sources), they may suffer impaired nervous system development. More than one million children under the age of six have blood lead levels that may place them at risk, and children living in poverty are disproportionately affected. Public health strategies have been stymied by a lack of practical, proven prevention methods. This study, carried out in Jersey City, New Jersey, demonstrated an effective strategy for reducing lead exposure. In families that received education about reducing exposure and whose homes were treated biweekly (by vacuuming with a high efficiency vacuum cleaner and by mopping uncarpeted surfaces), children's blood lead levels decreased 17 percent over one to two years.

Where Do We Go From Here?

ORD is currently conducting or planning many other activities to understand and lessen the environmental risks children face. Examples include the following:

- Based on lessons in study design and implementation learned from the two children's exposure pilot studies described previously, ORD is planning a large-scale extension of the pilots that will allow for more definitive conclusions to be drawn about children's exposure to persistent chemicals.
- ORD researchers are collaborating with the Minnesota Department of Health and the University of Minnesota (under the STAR program) to study children's exposure to pesticides through their diet, the air, and skin contact. The STAR program is also sponsoring research on pesticide exposure among children in Arizona, California, and Washington state.
- ORD is supporting the National Health and Nutrition Examination Survey (NHANES-IV), conducted by the CDC, so that information on children's exposure to certain pesticides and other environmental contaminants is collected.
- ORD scientists are studying the mold *Stachybotras* as a model for assessing and managing risks from indoor molds. *Stachybotras* has been implicated in the onset of sometimes fatal pulmonary hemorrhaging in infants and, like other molds, may play a role in childhood asthma.
- In partnership with the National Institute of Environmental Health Sciences, ORD selected eight academic institutions in 1998 to establish Centers of Excellence in Children's Environmental Health and Disease Prevention. Three institutions are focusing on pesticide risks, and the other five are focusing on the role of pollutants in inducing or exacerbating childhood asthma.
- Through EPA's Risk Assessment Forum, ORD is contributing to the development of guidance for assessing environmental risks to children.

7. Harmful Algal Blooms

If you visit coastal areas, you may have seen a sign like this one:

DANGER: Area Closed: Shellfish in this area contain toxins and are not safe for use as food.

Warnings like these have become more common in coastal areas around the United States. You may ask, "What is poisoning coastal aquatic life?" Often, the culprits are certain types of algae. While most algae are not harmful and form the base of the ocean's food web, under certain conditions some species can proliferate or "bloom," causing what is termed a harmful algal bloom (HAB). HABs can include some red tides, brown tides, and other potentially toxic organisms such as *Pfiesteria*.

Recently, the incidence and types of HABs have been increasing in U.S. coastal waters, potentially threatening humans, marine life, and economic resources in almost every coastal state. While the factors contributing to the proliferation of HABs are poorly understood, they may include nutrient enrichment or input of other pollutants by humans; species transport via ship ballast water; long-term climatic shifts; natural species dispersal; or even our increased abilities to detect new toxins and toxic events. In addition, blue-green algae (i.e., cyanobacteria) blooms are thought to be a growing problem in ground water, potentially threatening drinking water supplies.

Many of the species that form HABs produce potent neurotoxins that are known to cause serious human illnesses (e.g., amnesic shellfish poisoning) through ingestion of contaminated seafood, and in some cases through direct contact with seawater and inhalation of aerosolized toxin. Figure 7-1 shows the different types of human illnesses caused by HABs and where they have occurred in coastal areas around the United States. HAB toxins have been implicated in large-scale mortalities of fish, birds, manatees and other aquatic animals. *Pfiesteria* has been linked to fish kills, diseased fish, and human health problems from Delaware to North Carolina.

Other blooms do not produce toxins, but they can reduce the amount of light or oxygen in the water. This shading or depletion of oxygen can damage coral reefs and sea grass beds. Fish kills, beach cleanup, closures of contaminated commercial shellfish beds, toxin monitoring programs, and loss of tourism caused by HABs have caused large economic losses.

Focusing ORD's Current Research and Implementing the National HAB Strategy

In response to the growing concerns over HABs, EPA and other federal agencies implemented a jointly-funded interagency research program, the

Figure 7-1. Cumulative map showing locations of major HAB-related events along the coastal United States. Events include human illnesses (shellfish and fish poisoning), microorganism outbreaks, and loss of fish, birds, mammals, and vegetation. Source: NOAA COP/National HAB Office-WHOI.

Ecology and Oceanography of Harmful Algal Blooms (ECOHAB). This program, which is funded under the STAR Program within EPA, is designed to increase the understanding of all aspects of the ecology and oceanography of HABs.

The ECOHAB effort complements ORD's intramural research program devoted to HABs. Together these efforts are contributing to addressing critical research gaps and uncertainties in the causes and impacts of HABs on ecosystems and human health. ORD's HAB research strategy is the outcome of an ORD-sponsored workshop held in Florida in October 1997, in which leading experts from federal and state agencies and academic institutes met with EPA personnel. Goals of the strategy are to: 1) improve EPA's capability to provide a unified assessment of the risks of HABs by understanding effects on ecological condition and human health; 2) predict the occurrence of HABs by better understanding the causes of blooms and the relationships with coastal nutrient enrichment; 3) facilitate rapid response to HAB events by developing techniques for real-time detection of blooms and related potential impacts; and 4) evaluate potential management strategies to mitigate, control, and prevent HAB occurrences and their impacts. ORD has built a state-of-the-art laboratory culture facility for HABs in Florida to achieve these research goals and objectives.

Advancing the Science

To further support ORD's HAB research strategy, ORD has conducted research to better understand the potential adverse health effects of harmful algae. In one recent study, ORD investigated whether contact with estuarine waters where *Pfiesteria* is killing fish could adversely affect vision. A visual assessment performed on a group of fishermen found preliminary evidence that exposure to these waters adversely affected their ability to detect visual patterns. Because the fishermen had not been recently exposed to fish kills, the data suggest that the effects may be persistent. Another series of studies at Duke University, in collaboration with scientists in ORD, reinforced this finding when it showed learning impairments in lab rats exposed to *Pfiesteria* similar to problems experienced by people who have experienced significant exposure to *Pfiesteria*.

Where Do We Go From Here?

Highlights of ORD HAB research to achieve the objectives of its research strategy include:

- *Predict occurrence of HABs*. FY97 STAR grants are investigating the causes of specific types of blooms (e.g., blue-green algae blooms, at the University of Guam), and learning more about specific problem algal species (e.g., *Pfiesteria*, at North Carolina State University). ORD scientists have been working on the HAB problem in affected areas, including research and modeling, to determine some of the environmental factors critical in regulating population growth and toxin production in the Gulf of Mexico and on the Neuse River of North Carolina. This research is contributing to our ability to predict outbreaks and to control them when they occur.
- *Effects on ecological condition and human health*. ORD is cooperating with several federal and state agencies to monitor the ecological condition of Mid-Atlantic estuaries, including the Chesapeake and Delaware Bays. ORD scientists are helping several states identify potential adverse human health effects from exposure to toxins possibly produced by *Pfisteria*-like organisms. Other studies continue to characterize effects, including perception and memory effects, using animal models, as well as to verify effects on human vision.
- *Facilitate rapid response to HAB events*. ORD scientists are cooperating with the Florida Department of Environmental Protection under a STAR-funded grant to determine the factors leading to the formation and movement of toxic *Gymnodinium breve* blooms in the Gulf of Mexico. This could lead to potential HAB control and prevention strategies. ORD scientists are also collaborating with NOAA and the Naval Research Laboratory to identify and apply unique signatures of red tide species to monitor and track blooms in the Gulf of Mexico using remote sensing.
- *Control and prevent HABs*. FY98 STAR grants included funding methods to determine the feasibility of controlling HABs (e.g., work by the Woods Hole Oceanographic Institution on using clays to remove cells from infected waters) and to improve detection of HABs (e.g., work by the University of Maryland to develop a DNA-based assay for detecting *Pfiesteria*).

8. Pollution Prevention

The last time you opened a bag of potato chips, you probably didn't give much thought to how the bag was made. But preparing food packaging involves a number of steps and chemicals that, given the millions of packages produced each year, can add up to appreciable environmental impacts. For example, printing labels for foods and other consumer goods often involves the use of chemical solvents that contribute to ozone pollution when they evaporate and interact in the atmosphere with sunlight. Some solvents can be toxic when inhaled as well.

Research by Sigma Technologies International, Inc., with funding from ORD under the Small Business Innovative Research (SBIR) program, has recently resulted in technology with potential to reduce the environmental impacts of food packaging by eliminating inks that depend on organic solvents such as toluene. Sigma Technologies has developed inexpensive, high-speed technology and equipment for treating plastic film surfaces so that water-based inks or inks that employ no solvents at all can be used in printing packages. The technology has now been adopted by a major snack-food processor.

This kind of research is part of an approach to environmental protection known as *pollution prevention*. Pollution prevention has been embraced by EPA as the preferred way to address human health and environmental risks since passage of the Pollution Prevention Act of 1990. Pollution prevention differs from traditional, "end-of-the-pipe" approaches to controlling environmental pollution that address wastes after they have already been created, such as sending them to waste disposal facilities. Instead, it involves carefully analyzing pollution sources and seeking creative ways to avoid generating wastes in the first place. Replacing a toxic chemical with a less toxic one during manufacture is one example of pollution prevention. Another example is modifying an industrial practice so that it is more efficient, resulting in less production of waste materials. "Green Chemistry" – the development and introduction of new, less toxic chemicals into industry – is a rapidly growing field of pollution prevention.

Over the past decade, ORD has supported hundreds of pollution prevention projects and studies. Recent areas of focus of ORD's laboratories have been green chemistry, development of membrane technologies for purifying waste streams, cleaner industrial process and design, and benign solvents. Another important component of ORD's pollution prevention efforts is the Technology for a Sustainable Environment program (TSE), conducted through ORD's STAR program in concert with the National Science Foundation. Competitive grants are awarded to universities and other nonprofit organizations to support fundamental and applied research related to pollution prevention in industrial processes, methodologies, and technologies.

Recent Accomplishments

Use of More Environmentally Benign Solvents

Several recent ORD projects have examined solvents. The use of solvents goes well beyond food packaging; more than 30 billion pounds of organic solvents and solvents containing halogens (chlorine and related elements) are used worldwide each year in a myriad of industrial processes and as cleaning agents. Funded in part by a TSE grant, a researcher at the University of North Carolina has developed a new technique that allows the use of liquid carbon dioxide (CO_2) to replace solvents such as perchloroethylene in parts cleaning for industry and electronics and in dry cleaning. A researcher at the University of Notre Dame has used a TSE grant to study practical applications of solvents such as CO_2 when in the form of supercritical fluids (liquids heated above their boiling points). ORD has also developed a software tool to enable manufacturers to design more benign solvents or solvent mixtures for their operations. Called PARIS II, the "Program for Assisting in the Replacement of Industrial Solvents," it will soon be available to businesses.

Green Chemistry

In the area of green chemistry, ORD has successfully demonstrated a novel method for synthesizing chemicals using ultraviolet light and a special titanium dioxide catalyst developed by the University of Cincinnati. This process has potential as a clean method for manufacturing many oxychemicals, which constitute a large class of commercially significant chemicals currently made by less clean technologies. Through a TSE grant, researchers at the University of Kansas examined a class of reactions known as "alkylation" used in formulating gasoline and other industrial processes. These reactions traditionally use liquid hydrofluoric acid or sulfuric acid, which pose environmental and safety concerns because of the dangers from spills and the need for disposal of toxic wastes. Solid acid catalysts are potentially safer alternatives, but they tend to deactivate rapidly due to the formation of 'coke' deposits. The University of Kansas researchers have demonstrated a method for extending the life of solid acid catalysts by using supercritical fluids to remove coke precursors. This method may eliminate a major technological barrier to the use of safer catalysts in alkylation.

Membrane Technology to Reduce Pollution

Synthetic membranes are becoming increasingly important in wastewater treatment and a variety of other applications. ORD has worked with the University of Kentucky to develop a microfiltration membrane to remove toxic metals from waste streams, which may prove useful at both contaminated waste sites and in manufacturing. The approach involves incorporating low-cost materials into the membrane to capture metals, thereby preventing pollution from entering the environment. ORD has also developed a membrane technology (patent recently awarded) that will have significant potential in recovering volatile organic compounds for recycling from mixtures with surfactants.

Cleaner Process and Design

ORD is working to help industry reduce emissions from the manufacturing process, which can be a major source of pollution. For example, ORD has validated a technology that greatly reduces chromium emissions from hard chrome metal plating baths by using a class of fluorinated fume suppressants. Already commercially adopted by several companies, EPA will recommend this technology for complying with the Clean Air Act. ORD has also developed a software tool known as the Waste Reduction (WAR) algorithm, which can be used in analyzing the pollution impacts of various manufacturing process options to design one with the least adverse environmental impact (Figure 8-1). WAR will soon be available to businesses.

Where Do We Go From Here?

In September 1998, ORD published the *Pollution Prevention Research Strategy* (www.epa.gov/ORD/WebPubs/final/) that provides the framework for implementing a program of systematic research and development activities to carry pollution prevention well into the future. ORD's pollution prevention research program will have four main objectives: (1) delivering broadly applicable tools and methodologies; (2) developing and transferring pollution prevention technologies and approaches; (3) verifying selected pollution prevention technologies; and (4) conducting research to address economic, social, and behavioral aspects of pollution prevention.

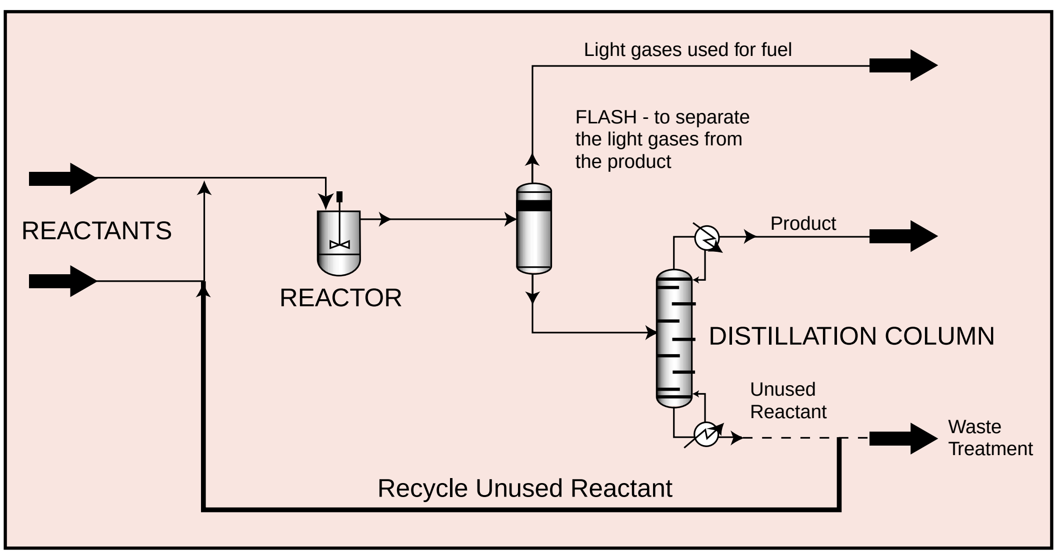


Figure 8-1. The Waste Reduction (WAR) algorithm uses process information to evaluate the environmental friendliness of a process design and to identify areas for pollution prevention, as shown in this simplified process flow diagram.

9. U.S.-Mexico Border Environmental Health

Figure 9-1. The border zone where the United States and Mexico are working together to solve environmental problems (as defined by the 1983 La Paz agreement). Source: modified from the report *United States-Mexico Environmental Indicators 1997.*

Mexico and the United States share a border that stretches more than 3,000 kilometers (nearly 2,000 miles) from the Pacific Ocean to the Gulf of Mexico. Within the zone that extends 100 km (62 miles) on each side of the border (Figure 9-1), the distinct social and economic features of the two countries converge and blend. Through trade, migration, and shared natural resources, the destinies of communities on both sides of the border are tightly interwoven. Rapid population growth over the past hundred years is one shared feature of the border area, with more than six million people now inhabiting the U.S. side of the border and more than four million on the Mexican side.

Rising commerce between the United States and Mexico has contributed to rapid industrialization of the border area, especially in the form of "maquiladoras" (manufacturing plants) in Mexico. More than 1,700 maquiladoras employ over 700,000 workers in the border area. While economic opportunities have improved for residents on both sides of the border, industrialization and population growth have placed a great strain on infrastructure and resources such as adequate housing, safe drinking water, clean air, and effective wastewater treatment. Until recently, for example, millions of gallons of raw sewage entered the Tijuana River each day. Such environmental stresses have caused or are suspected of having played a role in a variety of reported health problems such as elevated lead exposure in children, hepatitis, pesticide poisonings, childhood asthma, and various infectious gastrointestinal diseases.

With the interrelated nature of border communities and the fact that pollution does not respect political boundaries, the governments of Mexico and the United States have recognized that they must work together to solve environmental problems that affect communities on both sides of the border. The La Paz Agreement, signed by the Presidents of the United States and Mexico in 1983, intensified efforts to protect the environment along the U.S.-Mexico border. Mutual cooperation has led to projects such as upgrading wastewater and solid waste treatment capabilities. A new phase of addressing shared problems commenced in 1996 with the announcement of the Border XXI Program to build on the work of the La Paz agreement.

ORD's Role

ORD is involved in U.S.-Mexico border issues through the Environmental Health Workgroup (EHWG), which is co-chaired by ORD, the U.S. Department of Health and Human Services (HHS), and the Mexico Secretariat of Health (SSA). The EHWG is one of three new workgroups created by Border XXI to augment a set of six workgroups already established to address areas such as air and water. It evolved from an Interagency Coordinating Committee established in 1992 by EPA, HHS, and agencies of the U.S. border states. The EHWG seeks to improve the capacity of state, tribal, and local agencies on both sides of the border to assess and respond to health and environmental threats; improve opportunities for stakeholders in the border area to participate in environmental health initiatives; and prevent health and environmental problems through public education.

Recent Accomplishments

Under the auspices of the EHWG and its predecessor, ORD has funded and participated in numerous projects. One important accomplishment involved studying children's exposure to lead. Excessive lead exposure can impair nervous system development. Children in the border region may be exposed to lead through sources not commonly found in other parts of the United States, such as lead-glazed pottery used for cooking and storing food. Beginning in 1997-1998, the EHWG screened children's blood lead levels in the Arizona-Sonora, Tijuana, and New Mexico-Chihuahua border regions. The program introduced a new technology to the border area, a hand-held device for determining blood lead levels in the field. Results to date suggest that elevated blood lead levels are not pervasive among children living in the regions, though problems associated with specific contaminated sites exist.

Another effort has involved identifying areas where infants and young children may be at risk from agricultural pesticide exposure. To identify such areas, information on agricultural areas, pesticide use locations, and locations where children are present must be combined. ORD and other EHWG members established a Geographical Information Systems (GIS) workgroup to accomplish this task and similar projects on environmental health issues of concern. GIS is a computer-based approach for layering different types of information onto a single map so that patterns and relationships can be examined. The workgroup has developed standardized maps for both sides of the border and an inventory of existing environmental, population, and health datasets for the region. Using the maps, pilot screening studies to identify potential high priority areas for children's pesticide exposure are underway. The effort, which also included preparing a report for environmental health practitioners on how they can use GIS, has built the capacity for border states to continue their own GIS work.

Another ORD-supported effort to strengthen the capabilities of individuals and institutions in the border region to respond to environmental health issues is the "Advanced Training" program. This binational program focuses on training and education in the areas of environmental and occupational toxicology, epidemiology, and engineering, and risk communication. During 1997-98, scholarships were awarded to public health workers to obtain advanced degrees in epidemiology and six short courses were carried out in Mexico on a variety of environmental health topics.

ORD also conducted a study to find out if air pollutants were moving across the border from Mexico into the Lower Rio Grande Valley of Texas. Overall, transport of air pollution across the border did not appear to adversely affect air quality on the Texas side of the Lower Rio Grande Valley. Levels of air pollution were similar to or lower than other urban and rural areas in Texas and elsewhere. In addition to providing a better understanding of current air quality, the findings may be useful to compare to future levels of air pollution to see how conditions of the Valley are changing.

Where Do We Go From Here?

The EHWG has also pursued a number of other projects that are continuing beyond 1998, including:

- Assessing the risks to children from exposure to multiple pesticides from a variety of pathways, including food, soil, and dust.
- Completing the Texas Border Health Survey, a study of the health and environmental conditions along the Texas border.
- Developing an Environmental Health Yellow Pages to facilitate access to quality health and environmental information in border communities.
- Assessing the relationship between air quality and respiratory health in children in the El Paso-Ciudad Juarez area.
- Developing a small research grants and training program and an environmental health education program for health care providers to further strengthen institutional capacity.

The Workgroup is now implementing a new vision that expands its original focus by strengthening cross linkages with other Border XXI workgroups. For example, the EHWG is conducting joint planning exercises with the Air and Water Workgroups. The goal is to identify and test actual measures of health outcomes that can be used to assess the benefit of improvements in air and water quality, such as a decline in gastrointestinal illness after water treatment plants are upgraded. More information is available on their website (www.epa.gov/orsearth/).

10. Monitored Natural Attenuation

Long before humans began to recycle wastes and turn them into useful products, nature was already doing it. Organisms such as earthworms and bacteria have been recycling waste organic materials (e.g., dead leaves and other plant material) for millions of years. They do this by breaking them down into simpler compounds such as water, carbon dioxide, and minerals, which are used by other plants and animals. This process is called biodegradation. Natural attenuation takes advantage of biodegradation and other natural processes to reduce the toxicity, mobility, volume, or concentration of toxic materials and reduce the risk from these materials to humans and the environment. Examples of different natural attenuation processes are shown in Figure 10-1.

Ground water contamination by organic chemicals is a major national problem, with costs to clean up (remediate) contaminated water ranging into the hundreds of billions of dollars. Because fewer remediation options exist for ground water than other media such as soil, and it is technically difficult and extraordinarily expensive to clean up ground water, there is wide interest in using natural attenuation for ground water contamination problems. Although organisms in ground water can degrade many kinds of chemicals, they can be overwhelmed if the load of waste material they receive is too great. This happens when wastes, such as solvents, are improperly disposed or when fuels leak out of underground storage tanks, acting as a continuing source of contamination. Even in these cases, biodegradation may occur at the edge of the contaminated area due to dilution, limiting further movement of contaminants in the environment.

If a contamination source can be controlled, natural attenuation processes, combined with a carefully designed continuous monitoring program, may be a cost-effective approach for cleaning up contami-

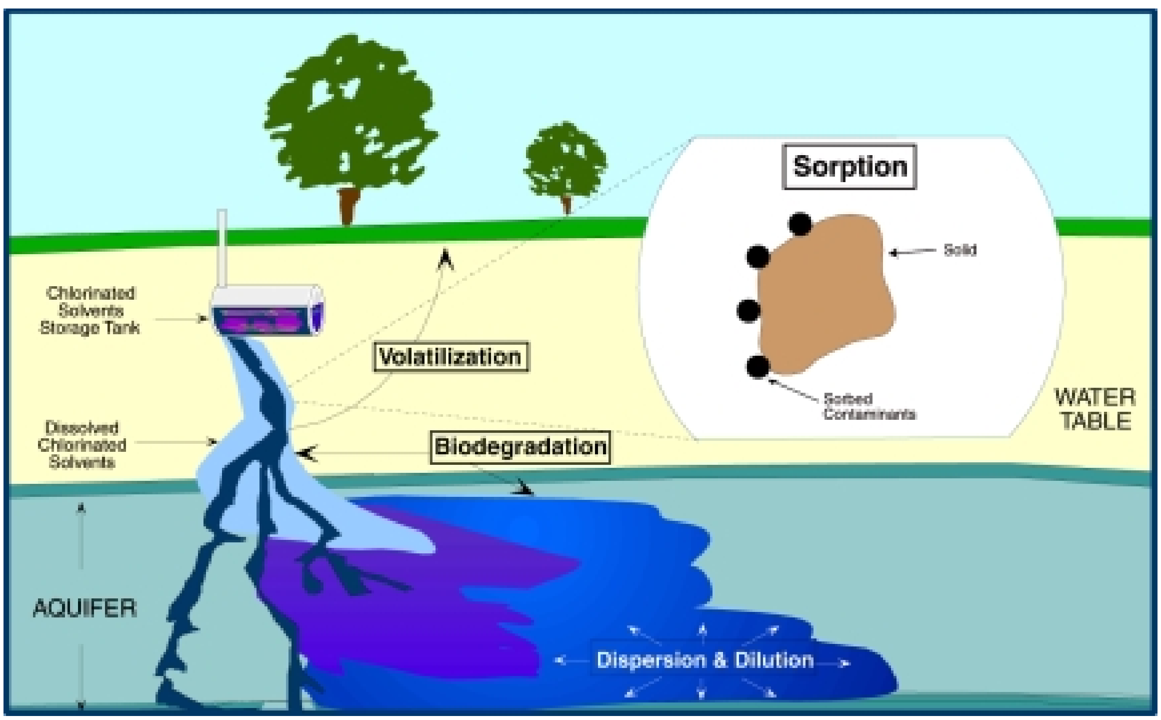


Figure 10-1. Natural attenuation processes may include: biodegradation (breakdown of waste organic materials by microorganisms into simpler compounds such as water and carbon dioxide); sorption (adherence of a contaminant to a solid); volatilization (evaporation); chemical reactions; and dispersion and dilution. This figure depicts these processes on dissolved chlorinated solvents leaking from an underground storage tank.

nated ground water. This approach is called monitored natural attenuation (MNA). Monitoring the natural attenuation processes at a contaminated site is key to successfully using this approach, because it determines whether natural attenuation is actually occurring and, if so, at what rate. Natural attenuation is monitored by collecting water samples from wells strategically placed in and around the contaminated area.

ORD's Research Program

ORD's extensive research program dates to the mid-1980s and is considered a leader in researching MNA of organic chemicals. During the 1990s, ORD scientists and other researchers found that natural attenuation of organic chemicals in ground water was much more extensive than previously believed. As a result, many site owners and others affected by contaminated ground water became interested in natural attenuation and began submitting proposals for meeting site cleanup standards by relying on natural attenuation to regulatory agencies. However, technical and regulatory guidance on the consistent evaluation and use of MNA did not yet exist, so potential cost savings from using MNA were not being realized.

Recent Accomplishments

ORD helped provide critically needed guidance in three ways. First, ORD worked with EPA's Office of Solid Waste and Emergency Response (OSWER) to develop an interim directive in 1998 to clarify EPA's policy on the use of natural attenuation in the clean-up of contaminated sites administered by EPA. Second, ORD developed a protocol in 1998 for MNA of fuels and chlorinated solvents in ground water to support the policy directive. The protocol focused on these contaminants because they were recognized as national problems in ground water and could be addressed by natural attenuation. The protocol provides guidance on collecting and evaluating data at a site to determine the extent to which natural attenuation is occurring, and whether it might be used as part or all of the site clean-up. Finally, ORD has been providing technical assistance and training to EPA Regional Offices and other federal organizations to implement MNA.

Key research findings on MNA that formed the basis for the protocol include:

- In general, sites should be screened for biodegradation potential before investing in a detailed data collection effort to evaluate natural attenuation
- Site subsurface conditions must be carefully evaluated
- For some plumes (the region containing the ground water contamination), MNA may be an option in only part of the plume
- Ground water contaminant transport and fate modeling can be important for evaluating MNA at a site but requires extensive data gathering for the model to be meaningful
- MNA is not likely to be appropriate if the plume is expanding
- Key to any MNA evaluation is an analysis of whether and to what extent humans and ecosystems are exposed to site contaminants

The protocol was a major step in implementing MNA at sites with ground water contaminated by chlorinated solvents and fuels in a way that is protective of human health and the environment. By following the protocol, tens to hundreds of millions of dollars in site cleanup costs can potentially be saved at Superfund, RCRA, and other waste sites. ORD collaborated with researchers from the U.S. Air Force, U.S. Geological Survey, and National Research Council Resident Research Associates in conducting this research.

Where Do We Go From Here?

MNA is potentially applicable to other ground water contamination problems, but more research is needed before it can be used in a manner that is protective of the environment. Current ORD research on MNA is focused on the fuel additive methyl tertiary-butyl ether (MTBE) and metals, particularly chromium and arsenic. ORD chose these chemicals because they are common ground water contaminants for which conventional remediation technologies are either not available or extremely expensive. MTBE is used in automotive fuels in most regions of the country, and appears to resist biodegradation. ORD is conducting extensive field and laboratory research to evaluate the natural attenuation of MTBE and to provide guidance to EPA's Office of Underground Storage Tanks.

Unlike organic compounds, metals cannot be broken down into other components. However, natural processes may immobilize metals in the subsurface, preventing further exposure to humans and ecosystems. ORD is conducting research to determine whether these processes may, under appropriate circumstances, be used to clean-up ground water contaminated with metals such as chromium or arsenic.

11. Global Change

Over the past two centuries, the Earth's atmosphere has changed appreciably. Largely due to combustion of fossil fuels, elimination of forests, and other human activities, compounds known as "greenhouse gases" have been accumulating in the atmosphere. Greenhouse gases include carbon dioxide (CO_2), methane, and chlorofluorocarbons (CFCs). CO_2 levels have increased by 30% over the past 200 years, and are thought to be higher now than at any time in more than 100,000 years. Greenhouse gases trap heat radiating from the Earth's surface, raising concerns that the planet may be warming.

The best available evidence indicates that worldwide temperatures have in fact risen. 1998 was the warmest year since widespread temperature records began in the late nineteenth century, according to the National Oceanic and Atmospheric Administration (NOAA), and seven of the ten warmest years on record have occurred in the 1990s (Figure 11-1). Rising sea levels and retreating glaciers also provide evidence that global temperatures are increasing.

While scientific consensus has emerged that human activities are affecting global climate, the causes and consequences of climate changes are far from completely understood. Climate is linked to a myriad of interconnected factors, including solar radiation, atmospheric gases and particles, cloud cover, global ocean currents, geological features, and polar ice sheets. Moreover, living organisms both respond to climate changes (e.g., by changing growth rates or moving to different areas) and modify them (e.g., by emitting gases and influencing water cycles). Human societies are no exception, reacting to and affecting climate in complicated ways.

Because of the vast scope and complexity of global changes, research must be integrated across scientific disciplines and national borders for scientific knowledge to advance effectively. Within the United States, the Global Change Research Act of 1990 led to the creation of a national research framework under the auspices of the U.S. Global Change Research Program (USGCRP), of which EPA is a member. Research findings from the United States and other countries are used by the Intergovernmental Panel on Climate Change (IPCC) to develop global assessments.

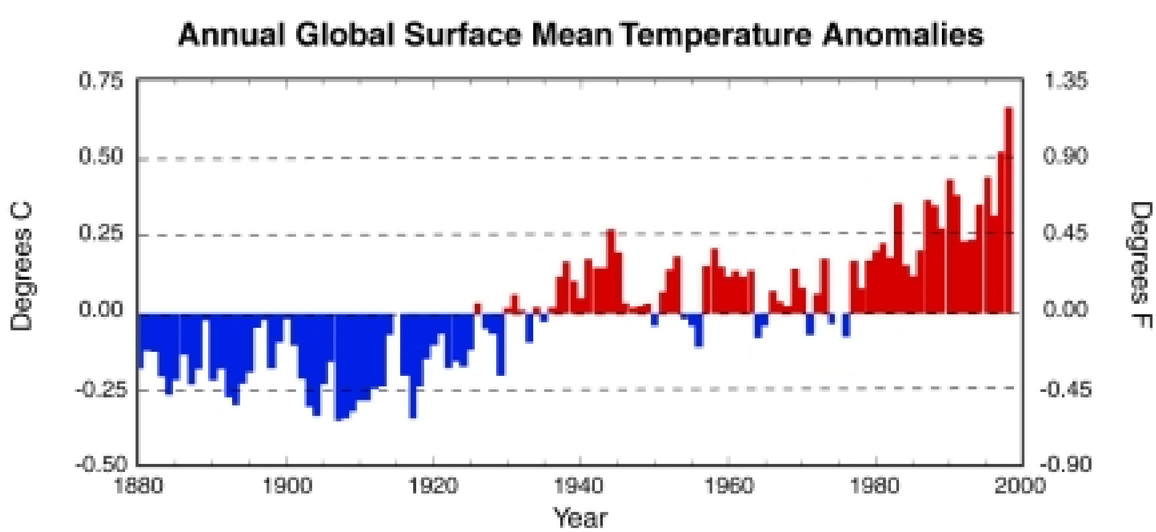


Figure 11-1. Combined global land and ocean temperature anomalies (deviations from the average) 1880-1998. "Zero degrees" represents the overall average during that time period. Seven of the ten warmest years have occurred in the 1990s. Source: National Climate Data Center/NESDIS/NOAA.

A New Direction for EPA Global Change Research

In 1998, ORD began a major redirection of its global change research program in response to changes in emphasis of the USGCRP and recommendations of external peer reviewers. Previously, ORD research largely pursued goals of understanding environmental processes (such as the carbon cycle) and developing technologies to reduce emissions of gases that contribute to global warming. Under the new program, ORD emphasizes assessing the human health, ecosystem, and socioeconomic consequences of global change. ORD's global change research encompasses not only climate change and climate variability, but also the effects of increasing ultraviolet radiation (due to stratospheric ozone depletion) and land use changes.

More specifically, ORD is examining the potential effects of global change on: (1) human health, including heat-related mortality and illness and the spread of infectious diseases, (2) air quality, (3) water quality and quantity, and (4) ecosystem health, including effects on biodiversity and important ecosystem services. These categories, which are interrelated, are being assessed in the context of other stressors not necessarily related to global change. A focal point of ORD's research efforts is leading public-private partnerships to complete assessments that will be part of the USGCRP's first National Assessment Report in 2000. ORD is directing the Great Lakes, Gulf Coast, and Mid-Atlantic Regional Assessments (three of the 19 regional assessments) and the Health Sector Assessment (one of six sectoral assessments). Other ongoing projects include the operation of a network of ultraviolet radiation monitors in National Parks in cooperation with the National Park Service and contribution to a report of the IPCC on land use change and forestry.

Recent Accomplishments

Because ORD recently redirected its global change program, most accomplishments will occur after the time frame of this report. Several recent achievements are worth noting, however. ORD and the U.S. Geological Survey jointly developed the North American Landscape Characterization database, which uses NASA Landsat satellite imagery to depict land cover and land use in the lower 48 states and Mexico from the 1970s through the 1990s. Researchers can analyze these data to see how land cover has changed over this time period and assess restoration opportunities. Additionally, ORD sponsored several public workshops during 1997 and 1998 for the health and regional assessments that will be part of the 2000 national assessment.

ORD's STAR grant to the Johns Hopkins University School of Public Health also yielded several noteworthy accomplishments. For example, researchers demonstrated that satellite maps of vegetative cover can be used to predict (and prevent) outbreaks of hantavirus more than nine months in advance. Hantavirus is a potentially deadly virus transmitted to people by rodents in the southwestern United States. Outbreaks are most likely when rodent populations flourish, which occurs during years with above-normal rainfall and resulting increased growth of vegetation. Changes in patterns of disease like this are examples of the possible consequences of changing climate. Johns Hopkins researchers also described connections between changes in climate and Lyme Disease in the U.S. mid-Atlantic; mosquito-borne dengue fever in the Brownsville, Texas area; and cholera in Peru.

ORD also completed research projects under its prior, more process-oriented global program. One noteworthy experiment, conducted over four years, examined the effects of elevated CO_2 and temperature on Douglas fir trees. The Douglas fir is an important species of Pacific Northwest forests valued for its timber. ORD researchers working in Corvallis, Oregon grew tree seedlings in a set of highly sophisticated growth chambers that contained the components of a forested ecosystem in miniature. The scientists were able to independently manipulate temperature and CO_2 concentration to examine the effects on soil characteristics and seedling growth. Both elevated temperature and CO_2 stimulated the release of CO_2 from the soil, suggesting that global warming might, over the long-term, reduce soil fertility and water holding capacity. Elevated temperatures (but not CO_2 alone) also altered bud growth and reduced shoot growth, resulting in deformed, shorter trees. These findings will be useful in predicting the impacts of global warming on Douglas fir trees.

12. Arsenic in Drinking Water

In 1996 Bangladesh suffered a national crisis when it was discovered that millions of its citizens were drinking water contaminated with arsenic. The source: wells constructed in the 1970s and 1980s to replace surface water supplies contaminated with disease-causing microorganisms. This and other events, including other large-scale arsenic poisonings from contaminated drinking water throughout the world (e.g., Taiwan, China, India, Mexico, and Chile) have heightened the need for addressing this health issue. Contamination of drinking water in the United States has been reported in several states, although the levels are generally much lower than those observed in Bangladesh. In some locations, however, concentrations in individual wells have been found to be extremely high.

Arsenic occurs naturally in the earth's crust and is a natural water contaminant in some areas. Human activities such as mining may also contribute to elevated levels in water. In addition to water, arsenic also occurs in foods. Arsenic can take different forms or species, which differ considerably in their ability to cause adverse health effects. Potential human health effects of ingested arsenic include skin and internal cancers (bladder, lung, liver, kidney, and prostate), cardiovascular disease, cerebrovascular disease, diabetes, and reproductive and developmental toxicity. EPA has classified arsenic as a human carcinogen through both ingestion and inhalation routes of exposure.

The 1986 Amendments to the Safe Drinking Water Act (SDWA) established a maximum contaminant level (MCL) of 50 µg/liter for arsenic. An MCL is the maximum allowed level of a contaminant in water delivered to any user of a public system serving 10 or more people. This arsenic MCL was adopted from a U.S. Public Health Service drinking water standard set in 1942, before modern cancer and other health related data on arsenic became available. As required by the SDWA Amendments of 1996, EPA is now reevaluating the MCL and will propose a new standard in 2000. Given this regulatory mandate, the potential health risks, and the high costs of treatment to remove arsenic from drinking water, research on the health effects of arsenic and cost-effective treatment technologies is a high priority for EPA.

ORD's Research Program

ORD's arsenic research program is contributing to the scientific and technical basis for the new arsenic standard. The 1998 *Research Plan for Arsenic in Drinking Water* describes a prioritized research agenda that has served as a guide to research conducted inside and outside of EPA (www.epa.gov/ORD/WebPubs/final/) High priority areas include measurement of different forms of arsenic in water, foods, and biological materials; research on internal cancers; development of tools and models to predict uptake of arsenic in humans; and evaluation of drinking water treatment technologies. ORD coordinates with organizations such as the American Water Works Association Research Foundation and the Association of California Water Agencies on arsenic research.

Recent Accomplishments

Understanding Human Exposure to Arsenic

The predominant inorganic arsenic species found in drinking waters are the trivalent (As^{+3}) and the pentavalent (As^{+5}) forms, or arsenite and arsenate, respectively. Because As^{+5} is easier to remove from drinking water, it is necessary to determine how much of each species is present before devising a treatment strategy. ORD researchers have successfully developed a sensitive method to measure both of these forms at very low concentrations (low parts-per-billion range).

To estimate the amount of arsenic in tissues in humans chronically exposed to arsenic, its metabolism and its elimination from the body must be understood. ORD research has shown that arsenic can be metabolized in the human gut, and that various factors, such as the amount of selenium in the diet, influence how arsenic is metabolized and eliminated. These insights are being used to develop a model of arsenic behavior in humans.

Insight Into How Arsenic Causes Cancer

Several ORD studies have focused on how arsenic causes cancer and other toxic effects. For example, ORD scientists discovered that when cells were exposed to arsenic, changes occurred to a specific gene, *p53*, that may reduce production of a protein that suppresses the growth of tumors. This in turn may predispose arsenic-exposed cells to transform into a cancerous state. Other ORD studies have shown that methyl arsenic, a form of arsenic that can be created within the body by methylation of inorganic arsenic, is an extremely potent enzyme inhibitor. These studies are significant because they differ from the current scientific view that methylation is simply a detoxification step.

Feasibility of Population Studies in the United States

In addition to research at the cellular level, ORD scientists have studied the health effects of arsenic in human populations in the United States and elsewhere in the world. ORD conducted a study in several Utah communities that historically have had long-term exposure to arsenic in drinking water. The contamination of groundwater in Utah is believed to have resulted from deposition of arsenic-contaminated ash and dust from formerly active volcanoes (Figure 12-1). This study showed that it is feasible to conduct an epidemiologic study of waterborne exposure to arsenic in the United States in which effects seen in studies of non-U.S. populations (e.g., skin and bladder cancer) can be evaluated.

Figure 12-1. Formerly active volcano in Utah, a source of arsenic contamination. The inset provides an interior view of the volcano.

Removing Arsenic From Drinking Water

ORD scientists evaluated two innovative treatment processes to remove arsenic from drinking water: ion exchange with brine (salt solution) recycle and iron coagulation with microfiltration. The ion exchange process uses a large amount of salt solution that ends up as waste. ORD-sponsored research at the University of Houston demonstrated that the waste solution can be reused over 20 times before it must be disposed, which saves costs and increases the efficiency of the process. The second treatment method involves the use of iron coagulant to absorb arsenic, which is then filtered from the water. Both processes were very cost effective for removing arsenic and practical for small systems.

Where Do We Go From Here?

In the area of health effects, the work in Utah has been expanded to a full-scale study that includes an evaluation of the use of urinary arsenic concentrations as a biomarker for exposure. ORD is also working in Chile with researchers from the University of Kentucky to evaluate the relationship between exposure to arsenic and potential effects in infants (mortality, birthweight, and prematurity) and in mothers (preeclampsia and gestational diabetes).

Scientists from ORD are collaborating with the Chinese Inner Mongolia Institute of Public Health to study the health effects of arsenic in drinking water and to compare inter-cultural differences that may impact its toxicity. EPA and other agencies sponsored the development of an International Tissue and Tumor Repository on Chronic Arsenosis at the Armed Forces Institute of Pathology in Washington, D.C. This repository will be useful in the study of chronic toxicity of arsenic, especially at the cellular and biochemical level.

In the area of exposure assessment, ORD scientists are developing analytical methods to more accurately measure arsenic in human biological samples and foods. These methods will provide information for assessing exposure and risk.

In the area of risk management, ORD scientists are evaluating the effectiveness of seven different oxidants (e.g., chlorine and ozone) in converting As^{+3} to the more readily removed As^{+5} as a pretreatment step for drinking water. ORD is also evaluating the performance of nine existing drinking water treatment plants in removing arsenic using conventional treatment methods, such as coagulation/filtration and ion exchange.

13. Economic and Decision-Making Research

On a clear day, the treeless summit of Mt. Washington in New Hampshire boasts a spectacular view of the surrounding White Mountains (Figure 13-1). Featuring many of the highest peaks in the Northeast, and forests ablaze with color during the fall foliage season, the scenic vistas of the White Mountains attract thousands of visitors each year. However, air pollution from countless sources — some nearby and some hundreds of miles away — can obscure these views and lessen the enjoyment of visitors. What is the economic impact of air pollution in this region? How much are these scenic vistas worth to people?

These kinds of questions are being examined through an ORD grant to the University of New Hampshire, University of Massachusetts, and the Appalachian Mountain Club. This grant is one of 25 STAR research grants underway or awarded during 1997-1998 to study methods for *valuing environmental benefits*. Unlike commodities like shoes or candy bars, which have well-established markets, placing a dollar value on environmental commodities such as clean air and water supplies is often controversial and difficult. Nevertheless, regulatory agencies like EPA need some way of gauging benefits in making decisions like whether further pollution controls are worth the costs placed on industry and consumers. In response to this need, ORD is sponsoring research on a variety of techniques for estimating the value of environmental benefits.

Research into valuing environmental benefits is one important component of ORD's economic and decision-making grants program, which is conducted in partnership with the National Science Foundation. Research in this field is an important complement to EPA's other research in disciplines such as toxicology and ecology. The findings from economic and decision-making research can help make EPA's programs to safeguard public health and the environment more effective and less costly to society.

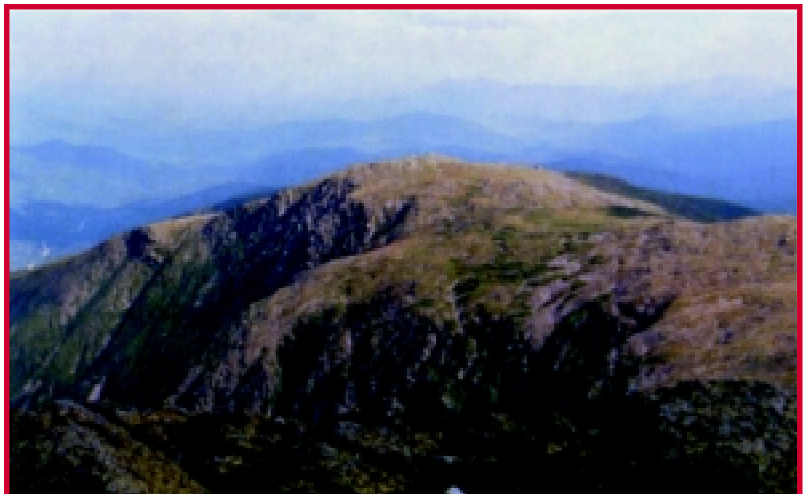


Figure 13-1. View of the White Mountains from Mt. Washington, New Hampshire.

Recent Accomplishments in Valuing Environmental Benefits

One of the principal methods for estimating the value of environmental benefits involves surveying people on how much they are willing to pay, or what they are willing to give up, to obtain an environmental improvement. To be reliable estimates of real values, survey instruments must be carefully designed and tested. Research under STAR grants has led to more reliable methods for designing and conducting valuation surveys. For example, research by Cornell University demonstrated that low-cost phone surveys could yield results at least as valid as more expensive face-to-face interviews. Duke University researchers found that surveyed respondents tend to be more willing to accept a public good (such as a new park) than cash as compensation for environmental harm. Researchers at the University of California at Berkeley demonstrated that the accuracy of the context of a question is more important than the kind of question used in surveys, based on comparisons to actual payments for environmental amenities. University of Georgia investigators evaluated methods for estimating the value of environmental benefits that included focus group discussions, interviews, and experimental payments combined with educational materials, and, like the Cornell researchers, found that context and education were of paramount importance in obtaining accurate values.

Other Economics Research Accomplishments

Some observers have criticized conventional measures of economic performance, such as a nation's gross domestic product (GDP), for counting practices that cause environmental harm as positive economic activity while failing to account for the environmental depletion that ultimately may lower standards of living. In response to these concerns, ORD has supported research through the STAR grants program on how to incorporate the value of natural resources and environmental quality into these aggregate economic measures to give a more accurate portrayal of the nation's quality of life. For example, the Colorado School of Mines developed more accurate estimates of the value of depletable energy and mineral resources to use in measures like the GDP. Other STAR grants have examined areas such as corporate decision making and policy alternatives. For instance, Resources for the Future examined different approaches for reducing pollution emissions. The research demonstrated methods for improving the efficiency of market-based approaches to pollution control, such as those that involve the buying and selling of emissions quotas.

Where Do We Go From Here?

A cornerstone of EPA's efforts to reinvent environmental policy is to find ways to accomplish environmental goals at lower costs, and experience has shown that using economic incentives and other market mechanisms is one way of doing so. Traditional, "command and control" regulations often require all pollution sources to meet the same emissions standards. This can be inefficient because some companies may find it extremely costly to meet the new standards, while others who are already in compliance have little incentive to improve. An alternative approach is to set overall emissions goals, and then let industries decide through the market how to meet them, using economic instruments such as tradable permits, fees, and taxes. ORD recently issued a grant solicitation for research into environmental management using these kinds of market approaches to implement more cost-effective approaches for controlling pollution.

Additionally, a recent EPA initiative focuses on the effects of environmental factors on children's health (see chapter on Children's Health for more information). Children may be more susceptible to pollutants and disease than adults, and they also differ from adults from an economic standpoint in that they would not be expected to pay to avoid health problems. As a result, estimating the economic costs and benefits of measures to protect children's health differs from making these estimates for adults. ORD is working with EPA's Office of Children's Health Protection to develop grants that will encourage research into the economic valuation of children's health.

Finally, ORD is initiating a joint solicitation with the Department of Justice (DOJ) to investigate determinants of corporate environmental performance and how various government interventions may impact this performance. Results of this research should help EPA, DOJ and the states better understand what kinds of incentives and deterrents are most effective in helping regulated entities achieve compliance with environmental laws.

14. Ecological Indicators

When you go to the doctor for a check-up, often one of the first things he or she will do is check your blood pressure. Your blood pressure reading is just one "indicator" of your health. By evaluating a combination of relevant indicators, a doctor can make a general assessment of your overall health. In much the same way, *ecological indicators* help ecologists assess the health or integrity of ecosystems. The extent of forests in a region or the types of fish able to live in a stream are two examples of ecological indicators. A natural ecosystem is so complex and dynamic that it is not feasible to monitor the status of all of the organisms, and all their interactions with their environment, that occur within the ecosystem. Ecological indicators are a way of sifting through this complexity, so that important signals about the condition of an ecosystem can be discerned. Consequently, ecological indicators are vital to scientists and resource managers in detecting changes in our environment and in pointing to the possible causes of these changes.

In some cases it is obvious what should comprise an ecological indicator, but often it takes a great deal of investigation and field testing to produce valid, reliable indicators. What might be the best indicators, for instance, of the condition of a stream — the number of fish? The types of fish? The types of stream insects? The vegetation growing along the stream banks? A combination of factors? Fully documented indicators exist for only a few types of North American ecosystems. For the past two decades, ORD has been performing research to develop needed ecological indicators. Currently, ORD is emphasizing the development of two types of indicators. The first is landscape indicators on local, regional, and national scales. The second is ecological indicators for aquatic systems, comprising streams, rivers, lakes, estuaries, and wetlands, including special or threatened ecosystems such as coral reefs. As a result of the efforts of ORD and other organizations, we are now better able to assess the state of our environment and meet the information needs of policymakers designing solutions to environmental problems.

Recent Accomplishments

Guidance Manual for Indicator Development. Recognizing the need for an overall framework for how to develop, test, and document indicators for a given ecosystem, an ORD-wide working group developed the *Evaluation Guidelines for Ecological Indicators*. The guidelines describe a four phase progression for developing an indicator: 1) developing a sound conceptual model; 2) evaluating the feasibility of gathering the data that comprise the indicator; 3) understanding the variability in the components of the indicator (such as measurement error and variability across time and space); and 4) ensuring that indicator results are clearly understood and useful to scientists and policy makers. Indicator development experts outside of EPA have cited the guidelines as a crucial step in assessing ecological condition. The guidelines are currently being used by ORD scientists and a technical manual is in press.

Landscape Indicators. Working in a number of locations around the country, ORD scientists have developed indicators of ecological condition from a broad, landscape scale. These landscape indicators range from conceptually simple (such as the percentage of forested land in an area) to more complex indicators made of several components (such as the percentage of crops on steep slopes with highly erodible soils), as shown in Figure 14-1. ORD has collaborated with other federal agencies to develop these indicators using satellite imagery as well as data collected on the ground. An example of the application of these indicators is ORD's 1998 report, *An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas*, which is described more fully in the chapter on the Mid-Atlantic Integrated Assessment. Some of the more than 30 indicators used in the report to assess watershed conditions include population density, road density, proportion of watershed with suitable interior forest habitat, and patterns of vegetation change from 1975 to 1990.

Under a STAR grant, a team of investigators led by Iowa State University has also developed ecological indicators that take into account landscape characteristics. These indicators were based on data gathered from satellite imagery on the spatial pattern and condition of mountain meadows in the Yellowstone National Park and Grand Teton National Park regions of Wyoming and Montana. The indicators can be used to predict the diversity of plants, birds, and butterflies in these meadows. Because meadow communities are highly sensitive to variations in precipitation and temperature, the indicators are a promising tool for quickly detecting ecological changes, such as those that may be brought on by climate change.

Estuary Indicators. Estuaries are vital resources that are home to many kinds of plants and animals, including commercially valuable fish and shellfish. Bottom-dwelling animals, or benthic organisms, help maintain water clarity in estuaries by filtering algae and sediment from the water and are a critical component of the estuarine food web. ORD applied and demonstrated an approach – known as the estuarine benthic index – for using benthic organisms as indicators of estuarine condition in a number of regions including the Mid-Atlantic, the Gulf of Mexico, and California. Just as the Dow Jones average is used to track the "condition" of the stock market, the index combines individual pieces of information into a single measure of the condition of benthic communities. ORD's 1998 report *Condition of the Mid-Atlantic Estuaries* (described in more detail in the chapter on the Mid-Atlantic Integrated Assessment) applied the index as one indicator of the ecological status of the Chesapeake Bay and other estuaries of the Mid-Atlantic.

Coral Reef Indicators. Under a STAR grant, researchers at the University of Guam developed indicators to assess impacts on coral reefs from sewage, sediment runoff, and pesticides. The indicators were based on measuring reproductive failure and disturbances of larval settling behavior in coral. Using these indicators, the scientists were able to recommend ways to prevent or reduce human impacts on reefs. Guam will implement one critical recommendation to stop particular sources of pollution such as sewage discharge and construction activity during the extremely brief period of time when coral reef fertilization occurs.

Where Do We Go From Here?

Future ORD ecological indicator research will continue to focus on developing landscape indicators and indicators for aquatic resources. Projects include:

- Landscape indicator development for the San Pedro Watershed of Arizona, the Tensas River Basin of Louisiana, and for the EMAP Western Pilot (see the Mid-Atlantic Integrated Assessment chapter for more information about the Western Pilot).
- Nationwide development and implementation of ecological indicators by EPA and other federal agencies to establish the current condition of all U.S. estuaries, provide a listing of stressors associated with impaired conditions, and inform environmental decisions to protect these critical resources.
- Continued work by academic researchers under more than 40 STAR grants for ecological indicators awarded.

Over time, as indicators are developed for individual ecological resources such as streams and estuaries, ORD will assess the extent to which the indicators can be used to document and assess ecological stressors that impact multiple resources. One such stressor is global climate change, which could involve changes in weather patterns and resulting shifts in distributions of organisms. Ultimately, the goal of ORD's research is to develop indicators that can be used to assess not only individual resources but also larger, interlinked ecological systems on continental and global scales.

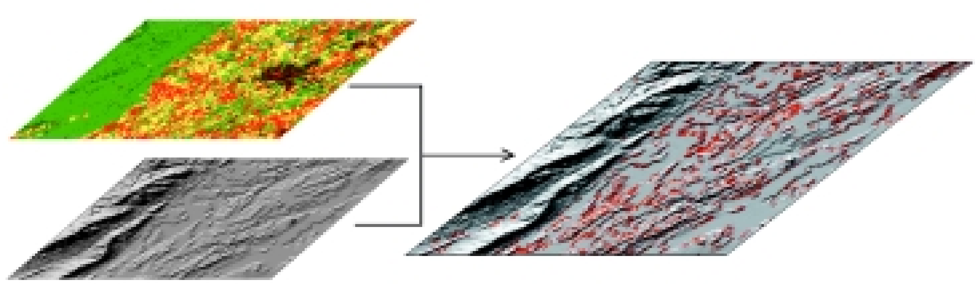


Figure 14-1. An example of an ecological indicator. Overlaying a land cover map (agriculture in red) with topography produces a new map showing agriculture on steep slopes. Agriculture on steep slopes indicates a risk to streams from soil erosion. Source: *An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas.*

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