RESEARCH STRATEGY

Global Change Research Program

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Office of Research and Development

U.S. Environmental Protection Agency

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EXECUTIVE SUMMARY

Earth's environment is constantly in flux. A complex interplay of natural processes and human activities foster wide-ranging change. Climate change and variability, change in land-use patterns, and change in UV radiation all are occurring on a global scale. The potential consequences of these global changes include adverse effects on human health, ecosystems, and socioeconomic well-being. Policy makers and resource managers recognize that decisions made today may have important long-term ramifications for the Earth system. Providing them with comprehensive assessments of potential consequences allows them to anticipate and to avoid or adapt to coming changes. The purpose of the Global Change Research Program is to provide scientific information to stakeholders and policy makers in order to support them as they decide whether and how to respond to the risks and opportunities presented by global change.

The *Research Strategy of the Global Change Research Program* articulates a vision of the Program's long-term goals for developing comprehensive assessments of global change issues and the research to support such efforts. The *Strategy* reflects the significant redirection of the Program towards an emphasis on assessing the consequences of global change. This new direction is a response to several factors: the Congressional mandate in the Global Change Research Act of 1990 that is strongly restated in the U.S. Global Change Research Program's (USGCRP) planning process (see *Our Changing Planet*, 1998, 1999, 2000); direction provided by external peer reviewers in a 1997 independent evaluation of ORD's Global Change Program draft research strategy; and the guidance contained in the National Research Council's *Pathways* report which set the stage for a reorientation of the USGCRP (1999).

The new focus is on areas where EPA enjoys a comparative advantage relative to other federal agencies and where EPA can truly make a difference.

Over the next decade, the Global Change Program plans a series of research and assessment activities culminating (in FY 2010) in a multi-sector, multi-region assessment of the consequences of global change in the US. These activities address those topics that represent the greatest risks to people and their environment, have demonstrated policy relevance, and show promise for extending the research community's assessment capabilities.

Assessment is an iterative, analytic process that engages both analysts and stakeholders in the evaluation and interpretation of the interactions of dynamic physical, biological, and social systems. The goal of assessment is to communicate insights about the possible consequences of global change and the potential for adaptive responses to the affected parties. Research and assessment are parallel and complementary activities. Assessment guides the foundation research program by identifying knowledge gaps and prioritizing research needs. Research, in turn, generates the flow of scientific and socioeconomic information needed in the assessment process. In planning for this ongoing, iterative research and assessment process, the Global Change Program ensures that the most timely topics are considered and that research needs and knowledge gaps are addressed.

The emphasis of the Program's research and assessment strategy is on understanding the risks and opportunities presented by global change, the interdependent and interactive effects of multiple stresses, the human dimensions of global change (human activities that catalyze as well as those that

respond to global change), and adaptation options. The Global Change Program is unique among ORD's research activities in that its goal is not to study current conditions and processes, but rather to build upon ongoing research to examine possible future changes and their influence on issues that are important to the public. ORD's air, water, ecosystems, and human health research programs provide monitoring, modeling, and process information that the Global Change Program can use to develop scenarios to assess possible impacts of changes in climate and land use on human health, ecosystems, and socio-economic well-being in the United States.

Table 1 provides a brief overview of the research and assessment activities planned for the Global Change Program through FY 2010. The four or five-year time periods allotted to each activity reflect the coupling of research and assessment efforts that comprise each assessment activity. This time period is somewhat arbitrary (reflecting the timing of project reports) and does not foreclose the option of continued work.

The other important feature of this plan is the flow of work within and across focus areas. Related activities are arranged in a logical sequence. For instance, the assessment of water-borne illnesses is conducted in parallel with assessments of aquatic ecosystems and of aquatic pollutants and microbial pathogens. Likewise, the human health assessment of the effects of tropospheric ozone under conditions of global change occurs after the air quality assessment of the global change impacts on ozone.

The Global Change Program has made a major commitment to and plans continued involvement in National Assessment activities organized through the USGCRP. The National Assessment is an ongoing process with scheduled reports to Congress in FY 2000, 2004, and 2008 (indicated by darker shading in Table 1) as mandated in the 1990 Global Change Research Act.

The first of four focus areas is Human Health. Since health is affected by a variety of social, economic, political, environmental, and technological factors, assessing the health impacts of global change is a complex challenge. As a result, health assessments in the Global Change Program will need to look beyond epidemiological and toxicological research to develop integrated health assessment frameworks that consider the effects of multiple stresses, their interactions, and adaptive responses. Along with three health assessments conducted in conjunction with the USGCRP National Assessment process, there will be research and assessment activities examining the consequences of global change on weather-related morbidity and vector- and water-borne diseases. Results from the air quality assessments will be utilized in the assessments of the health consequences associated with exposures to tropospheric ozone and particulate matter.

The second focus area is Ecosystem Health. The EPA's mission is not only to protect human health but also to safeguard the natural environment. EPA pledges to provide environmental protection that "contributes to making communities and ecosystems diverse, sustainable, and economically productive" (EPA 1997). Three research and assessment activities are planned that evaluate the effects of global change on 1) aquatic ecosystems (which may include lakes, rivers, streams, wetlands, and estuaries); 2) nonindigenous invasive species; and 3) ecosystem services. The assessment of aquatic ecosystems will contribute to the Water Quality assessment of biocriteria. The ecosystem services assessment will draw on work from the preceding ecosystem and water quality assessments. All three assessment activities will contribute to the National Assessment process.

The third focus area is Air Quality. Few studies have investigated the effect of global change on air quality. Examining the effects of global change on air quality is a logical focus of the Global Change Program, given EPA's legal mandates with respect to air pollution and substantial capability and expertise in modeling air quality and evaluating integrated responses. Assessments are planned that will examine the potential consequences of global change on tropospheric ozone and particulate matter. Each of these assessments is paired with a related Human Health assessment. Once again, these assessment activities are designed to support the National Assessment process.

The fourth focus area is Water Quality. Water quality is affected by changes in runoff following changes in precipitation and evapotranspiration

and/or changes in land use. ORD plans two assessments of the possible impacts of global change (climate and land-use change) on water quality. Both water quality assessments will either contribute to or benefit from Human Health and Ecosystems assessments. In addition, results from the assessment of pollutants and microbial pathogens will be used in the assessment of biocriteria. These assessment will also contribute to the National Assessment process.

The culmination of the 11 assessments and the National Assessment activities is a multi-sector, multi-region assessment of the consequences of global change for human health, ecosystems, and socioeconomic well-being in the United States scheduled for completion in FY2010. This assessment will synthesize and elaborate prior work.

Intramural and extramural research will provide crucial material to all of the assessments. Intramural efforts will be conducted through EPA's National Center for Environmental Assessment (NCEA), the National Exposures Research Lab (NERL), the National Health andEnvironmental Effects Research Lab (NHEERL), and the National Risk Management Research Lab (NRMRL). In addition, a significant portion of the program's resources are dedicated to extramural research grants administered by the National Center for Environmental Research (NCER) through the STAR (Science to Achieve Results) grants program. The STAR program focuses on two principal areas related to global change research — science to support assessments of the consequences of global change and human dimensions research.

Table 1. The flow of assessment and research activities in ORD's Global Change Research Program through FY 2010.

Research and Assessment Activities in the Global Change Research Program [a]		FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010
USGCRP National Assessments	Regional issues and human health [b]	■	▒	▒	▒	■	▒	▒	▒	■	▒	▒
HUMAN HEALTH	Climate change effects on weather-related morbidity [c]	▒	▒	▒	■							
	Climate and land-use change effects on water and vector-borne diseases			▒	▒	▒	■					
	Health effects of tropospheric ozone under global change					▒	▒	▒	■			
	Health effects of particulate matter under global change							▒	▒	▒	■	
ECOSYSTEMS	Global change effects on aquatic ecosystems		▒	▒	▒	■						
	Global change effects on nonindigenous invasive species				▒	▒	▒	■				
	Global change effects on ecosystem services [d]	■						▒	▒	▒	■	
AIR QUALITY	Global change effects on air quality — tropospheric ozone		▒	▒	▒	■						
	Global change effects on air quality — particulate matter					▒	▒	▒	■			
WATER QUALITY	Global change effects on water quality — pollutants and microbial pathogens		▒	▒	▒	▒	■					
	Global change effects on water quality — biocriteria					▒	▒	▒	▒	■		
MULTI-SECTOR	Synthesis assessment of the consequences of global change for human health, ecosystems, and social well-being in the US								▒	▒	▒	■

NOTE: The darker shading indicates the year in which an assessment report is due. Lighter shading indicates years in which the assessment and research process is underway.

[a] Additional activities occur each year through the extramural STAR grants program. However, the nature and scope of these research grants is difficult to anticipate prior to development of the Request for Applications. The STAR grant program contributes to the assessment process by sponsoring research to support assessment activities (e.g., the development of models of human dimensions or of the effects of multiple stressors) that benefits the scientific community at-large.

[B] The National Assessment process is ongoing. Thus, the representation of continual Global Change Program effort with reports to Congress required no less than every four years, in FY 2000, 2004, and 2008.

[c] Each activity outlined in the table assumes that a concurrent process of research and assessment will be carried out across a four or five year period resulting in a final assessment report as well as independent research reports. In addition to assessments of consequences of global change, analyses of the interplay of human dimensions and of possible adaptation responses will be included in assessment activities.

[d] The FY 2000 ecosystem services activity reflects completion of a preliminary analysis planned and initiated prior to FY 2000.

PREFACE

This document presents the research strategy for the Global Change Research Program of the Environmental Protection Agency's (EPA) Office of Research and Development (ORD). While the program is not new, this *Strategy* reflects a major redirection of the program. ORD began conducting research in Global Change in 1990 at the time of the passage of the *Global Change Research Act* and the establishment of the U.S. Global Change Research Program (USGCRP).

Much of the research from 1990-1996 was focused on atmospheric stabilization of the buildup of carbon dioxide and other greenhouse gases. This research emphasized terrestrial ecosystem-atmosphere carbon cycling; biomass burning detection; regional climate scenarios; comparative technology assessments and evaluations; specific greenhouse gas reduction technologies; effects research; and strategies for enhancing biospheric carbon storage. The research involved a combination of experimental, remote sensing, and modeling research, especially related to carbon cycling, greenhouse gas emissions, development of an Earth Systems Model, and control technologies. A list of publications from this era of the Global Change Program is included in Appendix A.

In 1997, three important events occurred which required ORD to re-evaluate its Global Change Research Program. First, an external peer review was critical of a program strategy written in 1996. Second, ORD experienced nearly a 50% reduction in appropriations for global change research. Third, the USGCRP requested that EPA redirect its program to emphasize the assessment of the consequences of global change.

After a decade of basic research on climate change, variability, and other global change, the agencies of the USGCRP believe it is time to focus on understanding the Earth system as a whole, the dynamics of environmental change, and the connection of that knowledge to societal needs. An effort is being made to eliminate programmatic overlap among USGCRP member agencies and to ensure that agencies contribute in those areas where they have the greatest comparative advantage. ORD's Global Change Program's advantage is in assessing the consequences of global change in the United States.

In response to the USGCRP request and to the findings of the 1997 peer review, ORD created the position of National Program Director for Global Change Research (in 1998) to guide the restructuring and to coordinate research and assessment activities across ORD Laboratories and Centers. Since that time, the program has undergone important changes. Global Change Program activities have been optimized given budget limitations to focus on those areas where EPA has the most to offer — assessments of the consequences of global change on air quality, water quality, human health, and ecosystem health. These four areas were selected because they are 1) areas where EPA has recognized expertise among government agencies; 2) areas that are consistent with the mandate and goals of the USGCRP; and 3) areas where EPA can make a difference. This strategy establishes a rationale for a coherent framework through which ORD will assess the consequences of global change in these four areas.

PURPOSE of the RESEARCH STRATEGY

Earth's environment is constantly changing due to the complex interplay of both natural processes and human activities. Evidence from scientific research has begun to show that humans play an important and expanding role as agents of global environmental change. Many of these changes cannot be reversed quickly, if at all, due to the long time cycles associated with many of the Earth's systems. The potential consequences of global change are wide-ranging and could adversely affect human health, ecological systems, and socioeconomic interests, all of which are vital to sustainable development.

Policy makers and resource managers have begun to recognize that decisions made today may have important long-term ramifications for the Earth system. As global change increasingly becomes an issue of national and international policy, the importance of research into the consequences of global change grows. Human adaptation to global environmental change will be critical in reducing adverse impacts and realizing the benefits of new opportunities. New scientific tools will be needed to understand and respond to global environmental risks. Global change research is an important investment for the future of the nation, its economy, and its citizens.

This document, the *Research Strategy for the Global Change Research Program*, articulates a vision for the long-term goals of the program. Since 1997, the Program has been redirected to become more assessment-oriented in response to: 1) Congressional mandates in the Global Change Research Act of 1990; 2) a 1997 external peer review of the program's research strategy; and 3) guidance provided in the National Research Council's "Pathways" report (1998). The *Research Strategy* is intended to be a living document and will be updated to remain current with end-user needs and with the state of the science in global change research.

Publication of this *Research Strategy* is consistent with requirements of the new Government Performance and Results Act (GPRA). GPRA calls for federal agencies to provide the Congress with "performance goals" and "performance measures" through which work is monitored and performance appraised. The Global Change Program has developed a timeline that establishes interim performance goals necessary to achieve the Program's long-term goal for 2010.

The *Research Strategy* describes the direction of the Program, *not* its implementation. As a result, it provides only the framework components of the research and assessment process, not a listing of specific projects. Detailed project implementation plans are documented and reviewed separately from the *Strategy*. They are developed annually based on Congressional budget appropriations. ORD's ability to achieve the long-term goals of the Global Change Research Program and to fulfill its role under the Global Change Research Act of 1990 will depend in part on adequate Congressional appropriations.

This document provides an overview of the critical activities of the Global Change Program for the next ten years. The first section, Context of the Global Change Program Strategy, describes how the goals and vision outlined in this *Strategy* relate to planning within ORD, the mandate of the USGCRP, and work in the international community. The next section, Program Capabilities, outlines the management structure and extramural and intramural capacities of the Program. Immediately following is a box that describes the Measures of Success used to evaluate the Program's effectiveness. The next section, Assessment Orientation, describes key strategic principles that guide the Program's research and assessment efforts. The final section, Program Focus Areas, identifies and provides justification for the four areas upon which the Program focuses its research and assessment activities — the potential effects of global change on human health, ecosystems, air quality, and water quality. It also outlines the criteria that are used to decide which projects will be undertaken by the Program.

CONTEXT of the GLOBAL CHANGE PROGRAM STRATEGY

Global Change Research Program Purpose

The purpose of the Global Change Research Program is to provide scientific information to stakeholders and policy makers to support them as they decide whether and how to respond to the risks and opportunities presented by global change. These assessments will not offer policy guidance — policy must reflect the values of those affected and the constraints of political and social institutions and fiscal realities — but will provide the scientific underpinnings to inform the policy making process.

Consistency of Research Strategy with ORD Strategic Plan and Responsiveness to GPRA

The development of this *Strategy* complements the Office of Research and Development's Strategic Planning Process. The ORD strategic vision is to provide the scientific foundation that supports EPA's mission. That mission is divided into four elements: 1) to perform research and development activities; 2) to provide technical support; 3) to integrate the work of ORD's scientific partners; and 4) to offer leadership in addressing emerging environmental issues (USEPA 1997a).

The Global Change Research Program has a similar, multi-part mission that is consistent with the ORD mission. The mission of the Global Change Program is to:

- improve the scientific basis for evaluating effects of global change in the context of other stressors and human dimensions;
- conduct assessments of the consequences of global environmental change; and,
- improve society's ability to effectively respond to the risks and opportunities presented by global change as they emerge.

The *Research Strategy* is also consistent with requirements of the Government Performance and Results Act (GPRA), which require agencies to provide the Congress with measurable "annual performance goals" and "performance measures." In response to GPRA, the Global Change Program has developed a timeline that establishes interim performance goals necessary to achieve the Program's long-term goal for 2010 (see Table 1).

The long-term goal of the Global Change Program is to understand and articulate, in terms that are meaningful for decision-makers and other stakeholders, the consequences of global environmental change for human health, ecosystems, and social well-being in the U.S. Global change is a broad concept that can include many things that influence the Earth system. To narrow the potential scope of the program while ensuring consistency with the short- and long-term objectives of the USGCRP, the Global Change Program will focus on the following stressors and interactions:

- *The potential consequences of climate change and climate variability*. EPA's focus on climate change and variability is in keeping with USGCRP's First National Assessment. Air and water quality — the protection of which is EPA's mandate — may be strongly influenced by climate change. Such effects must be understood to meet the Agency's basic mission.
- *The effects of UV radiation*. Here, EPA's primary concern is the effect of changes in UV radiation on ecosystems, their components, and the services they provide.
- *The effects of land-use changes*. Further understanding is needed regarding how to assess the underlying processes that determine how land-use change interacts with climate change to affect land cover, ecosystem services, hydrologic cycles, species distribution, biodiversity, and social and economic systems.

ORD's strategic plan articulates six long-term, overarching goals (see Table 2). These goals are intended to inform decisions about research directions for years to come. Together with more specific research objectives, the goals also provide greater accountability for results (as required by GPRA). The Global Change *Research Strategy* was developed with these goals in mind. Conducting assessments and the research to support assessments is consistent with ORD's long-term goals.

Table 2. Relationship of Assessment Orientation of Global Change Program to ORD's Long-Term Goals.

ORD's Long-Term Goals		Assessment Orientation of Global Change Program
Develop scientifically sound approaches to assess and characterize risks to human health and the environment	#	*Assess potential consequences of global change for human health, ecosystems, and social well-being*
Integrate human health and ecological assessment methods in comprehensive multimedia methods	#	*Assess global change in context of risks to multiple systems; integrate methods in holistic framework*
Provide common sense, cost-effective approaches to prevent and manage risks	#	*Conduct assessments to provide critical findings to stakeholders about the nature of global change risks and adaptation options*
Provide credible, state-of-the-science risk assessments, methods, models, and guidance	#	*Provide credible, state-of-the-science assessments of potential consequences of global change*
Exchange reliable risk assessment/risk management information with stakeholders	#	*Utilize assessment findings to communicate reliable risk information to stakeholders*
Provide leadership to identify emerging environmental issues, characterize risks associated with these issues, and develop ways to prevent or reduce risks	#	*Provide leadership in the conduct of assessments to characterize key risks associated with global change and to describe adaptive responses to reduce risks*

Support to EPA Regulatory and Regional Offices

The assessments described in this *Strategy* will support EPA's Program and Regional Offices by providing insights regarding possible future conditions of the resources within their oversight. For example, the Office of Air and Radiation has a strategic goal of bringing all areas of the country into attainment with the National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter (PM) by 2012 (USEPA 1997b). The Global Change Program plans an assessment of the consequences fo global change on tropospheric ozone and PM under different climate scenarios, including assessing the ability of communities to achieve the NAAQS. Health assessments will build on the air quality assessments to project potential health effects. The Global Change Program will work with the Program and Regional Offices to ensure that assessments address issues of concern.

The U.S. Global Change Research Program

The USGCRP was created as a Presidential Initiative in 1989 and formalized in 1990 with congressional passage of the Global Change Research Act (see Appendix B). The global change research activities of all participating federal agencies are coordinated to ensure that the overall goals of the USGCRP are achieved. At the same time, agencies are assigned responsibilities that are consistent with their own missions and take advantage of their respective areas of expertise (see Table 3) (USGCRP 1999). Interagency partnerships are encouraged and duplication of efforts avoided. Through the USGCRP, the global change research activities of multiple agencies are coordinated and "a comprehensive program of scientific research and assessment on the multiple issues presented by climatic and other changes in the Earth system" is supported (Subcommittee on Global Change Research, 1999, p.1). For additional information see www.usgcrp.gov.

EPA's Role in the U.S. Global Change Research Program

Among the USGCRP member agencies, EPA is responsible for assessing the potential consequences of global change on human health, the environment, and social well-being in the United States. The involvement of the EPA Global Change Program in the USGCRP is consistent with the National Academy of Sciences' recommendation to engage in "a formal process" to "identify and coordinate areas of research that are supported by multiple agencies" (NAS 1999). ORD's Global Change Program responded with a redirection towards a more assessment-oriented program in 1998.

National Assessment

The Global Change Research Act of 1990 mandates the preparation of periodic scientific assessments of the potential consequences of global change for the United States. The goal of the first National Assessment is to determine the regional and national implications of climate change and variability for the people, environment, and economy of the United

States in the context of other, non-climate (environmental, economic, and social) stresses. The first National Assessment emphasizes a process driven by the needs of stakeholders — persons best positioned to identify important information needs and optimal ways of responding. The National Assessment is founded on the principles of scientific excellence and openness.

The first National Assessment includes 19 geographic regions, five sectors (human health, coastal areas and marine resources, forests, agriculture, and water resources), and an overall synthesis. These different elements provide perspectives from multiple scales and for different audiences. Currently, EPA co-chairs the National Assessment Working Group (NAWG), the federal interagency group overseeing the Assessment Process.

Table 3. Major Focus Areas of USGCRP Agencies, by Program Element

	Agency								
Program Element	DOC/ NOAA	DOE	DOI/ USGS	EPA	HHS/ NIH	NASA	NSF	SI	USDA
Understanding the Earth's Climate System	!	!	!			!	!		
Atmospheric Composition & Chemistry	!	!				!	!		!
Global Water Cycle						!			
Carbon Cycle Science	!	!	!			!			!
Biology & Biochemistry of Ecosystems		!	!	!			!	!	!
Human Dimensions of Global Change (including Assessment of Consequences)				!	!			!	
Paleoenvironment/Paleoclimate							!	!	

(NOTE: Area was considered major if constituted 10% or more of agency spending on global change research. Source: *Our Changing Planet: The FY2000 U.S. Global Change Research Program*)

EPA also sponsors the Mid-Atlantic Regional Assessment, the Great Lakes Regional Assessment, the Gulf Coast Regional Assessment, and the Health Sector Assessment in this first National Assessment. The Global Change Program will be a major participant in subsequent National Assessments, which are to be conducted no less than every four years. Additional information on the National Assessment can be found at the USGCRP web-site (www.nacc. usgcrp.org).

Conducting assessments of the consequences of global change at regional scales is consistent with ORD's Ecological Research Strategy (Linthurst *et al.* 2000). ORD's ecological research program strives to understand relative ecological risks in the context of multiple stressors, at multiple scales and multiple levels of biological organization. The integrative techniques articulated in the Ecological Strategy suggest that research be conducted at "places" or regional-scale settings, such as the Mid-Atlantic, the Great Lakes or the Gulf Coast. EPA has long emphasized the importance of understanding environmental consequences from a regional perspective. Thus, this *Strategy* remains consistent with the Agency's strategic direction.

The International Policy Process: Involvement in

the Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to assess scientific information about climate change relevant to international and national policy formulation. The United States, through the USGCRP, has consistently played a leading role in the IPCC, by co-chairing working groups and by supporting the world's most comprehensive set of climate research activities. ORD's Global Change Program contributes to the IPCC effort directly through scientific information produced by EPA researchers and through involvement as lead and contributing authors, review coordinators and reviewers of IPCC Reports, and indirectly through participation in the National Assessment of the Potential Consequences of Climate Variability and Change for the United States. Additional information on the IPCC, the Second Assessment report, the upcoming Third Assessment report, and other IPCC Special Reports and Technical Papers is available at the IPCC web-site (www.ipcc.ch).

PROGRAM CAPABILITIES

National Program Director Leadership

The agency-wide GPRA goal for effective management guides the Global Change Program's internal management plan. Strong management encompasses "effective vision and leadership; sound management practices; results-based planning and budgeting; fiscal accountability; and quality customer service" (EPA 1999, p. x-1). Building an integrated program based on uniform objectives is key to implementing effective management in the Global Change Program. To provide leadership in this process, a National Program Director was appointed in 1998. Establishing overall leadership for the Global Change Program addressed a need for centralized program management identified by the peer review panel (1997) and reflects "ORD's strong commitment to specific emerging research efforts" (February 1999 memorandum from Assistant Administrator Norine E. Noonan announcing the National Program Director positions). The National Program Director is responsible for coordinating planning and implementation efforts (in conjunction with the Research Coordination Team), for resource allocation recommendations to the Executive Council (ORD senior management), for reporting on progress, and for programmatic review. The responsibility for program implementation remains with the lab or center conducting the activity.

Intramural Capabilities: Utilizing Global Change Program Labs and Centers

The Global Change Program is designed around both intramural and extramural components. The intramural component includes both research and assessment activities coordinated across multiple ORD laboratories and centers. The extramural component consists of grants administered through ORD's Science to Achieve Results (STAR) program. Deciding how Program work is best accomplished — whether through intramural or extramural activities — is based on several factors: 1) the type of work or expertise required; 2) the urgency of the need for a particular product; 3) the extent to which involving multiple institutions provides added value; 4) the opportunities for leveraging resources; and 5) the extent to which there is a need to support basic, independent research to advance the assessment capabilities of the scientific community at large. Guidance for cross-lab efforts is provided by a Research Coordination Team with representation from each of ORD's labs and centers. Specific projects undertaken by ORD labs and centers are identified by the Research Coordination Team every year and outlined in each lab's Annual Implementation Plan. An annual meeting of the multi-lab team provides an additional opportunity for reviewing program-wide work.

Each of EPA's labs and centers has specialized expertise. The use of these skills is coordinated by the National Program Director, in partnership with the Research Coordination Team, to meet the assessment goals outlined in Table 1. A detailed description of the specific assessments planned for each of the program's four focus areas appears later in this *Strategy*. The focus area discussions outline the specific steps that are necessary to complete the scheduled assessments and refer back to the following descriptions of lab and center capabilities.

The **National Exposures Research Laboratory's (NERL)** activities involve experimental and modeling research. The NERL's in-house research program provides the capability to assess the vulnerability of aquatic ecosystems and water quality to global change. In addition, the NERL has expertise in air quality modeling that can contribute to the assessment of the consequences of global change for air quality. Finally, NERL can contribute to the assessment of the exposure of ecosystems to UV radiation.

Through the NERL, the EPA Global Change Program currently supports (in cooperation with the National Park Service) a network of continuously operated stations monitoring UV radiation at a range of longitudes, latitudes, and elevations across the U.S. The UV monitoring network was established in 1992 to provide reliable data to 1) improve understanding of the

status and trends in UV flux, temporally and spatially, 2) to characterize the physical and chemical parameters that modify UV flux, and 3) to improve radiative transfer models and inferences that can be drawn from them, including consequences of UV exposure for human and ecological health. Data from these monitors make it possible to evaluate the intensity of and trends in UV radiation reaching the Earth's surface and can be used as input for human and ecological assessments.

An important component of global change over the next 30-40 years will be land use or land cover change in watersheds and basins. These changes, which are largely driven by human activities, will interact with other changes, such as climate and UV change, to alter aquatic ecosystem functioning and structure with concurrent effects on drinking water quality, diversity of aquatic life, and resilience to catastrophic flooding. NERL is focusing its expertise on the following issues related to global change: 1) development of landscape indicators and indicators of surface water conditions; 2) research into the interactions between aquatic ecosystem functioning and changes in climate, UV, and land use; and 3) evaluation of UV radiation exposure in aquatic ecosystems.

The **National Health and Environmental Effects Research Laboratory's (NHEERL)** in-house research program is focused primarily on improving capabilities to assess global change in two areas: 1) research on the effects of UV radiation on ecosystem health; and 2) research on the effects of global change on coastal ecosystems. These activities are coordinated with other USGCRP agencies, such as the U.S. Geological Survey, to ensure that EPA's efforts are not duplicative of other programs.

An important component of understanding the consequences to ecosystem health is evaluating the world-wide decline in amphibians. NHEERL will be conducting research into the interrelationships of UV radiation, exposures, chemical contamination, nonindigenous species, and climate change on the decline of amphibians and the occurrence of morphological malformations in populations in the upper Mid-west. It is plausible that multiple factors are at work and that climate change and UV radiation act as exacerbating stressors to chemical contamination and habitat loss.

Another component of NHEERL's research is in understanding the consequences of climate change on coastal ecosystems, specifically on the Gulf Coast and along the Atlantic Coast from the mid-Atlantic to New England. Research will focus on the interrelationships of multiple stressors on coral ecosystems in the Florida Keys and in evaluating the change in the environmental quality of estuaries and coastal watersheds along the Atlantic Coast. The changes in environmental quality reported from EPA's Environmental Monitoring and Assessment Program (EMAP) for the Atlantic Coast may be due, in part, to changes in the climate cycle (US EPA 1998). For example, climate change effects on sea level and changes in rainfall patterns can alter the water cycle in coastal watersheds. These changes can lead to increased nutrification and subsequent reduction in oxygen levels in the coastal estuaries. In turn, the altered system may result in conditions that favor invasive species over native organisms.

Researchers in the **National Risk Management Research Laboratory (NRMRL)** are focused on developing methods, models, and data required to assess the multiple or co-benefits of adaptation strategies needed to protect air and water quality under a variety of climate change scenarios. Their goal is to develop options for risk management (i.e. adaptation) that may be pursued in response to the potential consequences of climate change. NRMRL researchers are examining how climate-induced changes will impact other environmental problems that pose health and environmental risks such as tropospheric ozone and drinking water contamination while identifying approaches (both technological and socioeconomic) to adapt to those changes. Initial work will investigate the influence of future transportation fuel choices and renewable energy options and their relationship to climate change. In addition, NRMRL will study climate and land use change impacts on water quality.

Much of the infrastructure now in place to prevent or control releases of environmental

contaminants is based on ORD research. Expertise in developing and testing air pollution control, drinking water treatment, and wastewater treatment technologies as well as capabilities to model and analyze watersheds, surface water systems, storm water runoff, and groundwater systems can be utilized to assess the potential viability of adaptations to climate change. For example, existing expertise in air pollution control technology can be directly applied to identifying potential adaptation options for increased tropospheric ozone under conditions of climate change.

NRMRL has the capability for undertaking a variety of analyses relevant for assessments of co-control benefits, including 1) estimation of the amount and type of reduction in ozone precursors or particles that must be implemented to meet current National Ambient Air Quality Standards (NAAQS) under future climate conditions; 2) evaluation of how future technological and societal choices may alter global change impacts; 3) evaluation of how wastewater plan capabilities may be affected under various climate scenarios; and 4) evaluation of changes in water quality and aquatic habitat under different temperature and flow regimes associated with climate change. Drawing on results from extramural grants and EPA intramural programs, the **National Center for Environmental Assessment (NCEA)** is ultimately responsible for producing the assessments listed in Table 1. NCEA assessors engage both researchers and end-users to analyze, evaluate, and interpret information from multiple disciplines to draw conclusions that are both timely and useful for decision makers.

NCEA also is responsible for supporting and contributing to the Congressionally-mandated National Assessment process. This includes conducting multiple regional and sectoral assessments for inclusion in periodic reports to the Congress. EPA-sponsored assessments will continue to be conducted through public-private partnerships, engaging researchers from the academic community, decision makers, resource managers, and other affected stakeholders. In addition, NCEA is responsible for maintaining an orientation to stakeholder needs throughout the assessment process.

NCEA also has an important coordination function within the U.S. Global Change Research Program (USGCRP). The National Program Director, who resides in NCEA, is the Chair of the National Assessment Working Group (NAWG). The NAWG is composed of representatives of the relevant federal agencies that provide oversight to the National Assessment process. The NAWG is the principal interagency venue for these activities, linking agencies and offices of the federal government to the USGCRP and the National Assessment.

Extramural Capabilities: Utilizing the STAR Grants Program

In order to capitalize on expertise in the academic community, a significant portion of the program's resources is dedicated to extramural research grants administered through the STAR grants program. The STAR Program's support of long-term research promotes work in high-priority areas of science (identified in Agency and Program strategic plans). Managed by ORD's **National Center for Environmental Research (NCER)**, the STAR Program's role consists of competitively awarded grants offered through Requests for Applications (RFAs) and written to be consistent with and responsive to the Global Change Program's strategic plan. The STAR grants program focuses on two principal areas of global change research: 1) science to support assessments of consequences; and 2) human dimensions research. Extramural grants help the Global Change Program attain its long-term objectives and encourage scientific work supporting global change assessments. Because of the nature of the grants process, grants are not used to conduct assessments themselves. ORD has no authority to compel grantees to respond to stakeholder input (a key component of the assessment process), and the timing or needs of specific assessments cannot determine the requirements of grant-sponsored research.

Expert peer review by independent, external reviewers is used to evaluate proposals and subsequent work products. In this way, the Global Change Program's extramural research is responsive to the National Academy of Sciences' recommendations for the conduct of research under GPRA that "Federal agencies should use

expert review to assess the quality of research they support, the relevance of that research to their mission, and the leadership of the research" (NAS 1999).

The Integral Role of Stakeholders

Through the grants program and collaborations within the USGCRP and the IPCC, the Global Change Program builds strong relationships with scientific and stakeholder communities. The Global Change Program has ties to EPA Program and Regional offices, to other federal agencies (e.g., through involvement in the USGCRP and the National Assessment process), to the non-governmental and academic communities (e.g., through STAR grants), to the international scientific community (e.g., through IPCC assessments), and to stakeholders (including public health officials, water- and air-quality managers, natural resource managers, etc.).

As an assessment-oriented program, the Global Change Program is especially focused on stakeholder concerns. Interacting with stakeholders is essential to ensure that useful information is developed, that relevant stressors and effects are identified and investigated, and that policy-relevant results are effectively communicated. Stakeholder involvement has played a central role in the conduct of the first National Assessment. As USGCRP agencies plan for post-2000 assessment activities, they affirm that "close collaboration with ... resource managers, decision makers, and other stakeholders is essential to ensure that USGCRP assessments adequately and accurately incorporate and reflect the sensitivities, resilience, and realistic adaptation options of managed and natural systems" (National Assessment Working Group 1999).

The Global Change Program is committed to continuing efforts to maintain and expand stakeholder networks established during the first National Assessment by incorporating stakeholder components in intramural research and external assistance agreements and by developing a two-way flow of information through internet access to documents, data, and analytic tools. In addition, the Global Change Program engages stakeholders in workshops to develop long-term global change research plans for air and water quality, human health, and ecosystems.

Effectively Managing Information

In an environment in which global change issues are featured news, where information quality is uneven, where the subject matter is complex, and where uncertainty is considerable, the Global Change Program has an important role to play in information management. Just as the Agency has set management goals for quality customer service and goals for the expansion of Americans' right to know about their environment, the Global Change Program is committed to sharing information more broadly and in more ways than ever before. To that end, RFAs funded by the Global Change Program now require the investigator to release to the EPA, for public use, the data, tools, and documents produced during the period of the grant or cooperative agreement.

A publicly accessible website for the Program is currently being developed utilizing a linked database, the Environmental Information Management System (EIMS) (Shepanek 1997). (The EIMS database website is accessible at: http://www.epa.gov/eims/eims.html). The EIMS organizes descriptive information (metadata) for data sets, databases, documents, models, projects, and spatial data and provides a repository for scientific documentation accessible with standard Web browsers. The fully integrated EIMS database links data, documents, and tools by concept, project, location, and/or time frame.

The website will allow the Global Change Program to provide access to program products, including project descriptions, updates, and reports, other program documents, workshop announcements and proceedings, data, and analytic tools. Interactive tools and models support the decision and analytic needs of planners, resource managers, and other data users.

The products produced by the Global Change Program are subject to formal peer review (when review is appropriate), consistent with Agency-wide guidance (EPA 1998b). Finalized materials

are made available upon request and, as the Global website is expanded, will be available online as well. The Global Change Program will actively solicit the input of clients (Program and Regional offices, USGCRP agencies, and other stakeholders) and will partner with them to design more effective communication strategies.

MEASURES of PROGRAM SUCCESS

The *1997 Update to ORD's Strategic Plan* outlines four measures of success. These measures are appropriate yardsticks for measuring the performance and products of the Global Change Research Program.

Significance — Is the Global Change Program working on the right issues?

This is a measure that stakeholders help determine and the larger scientific community can help judge. Since stakeholder input is integral to the assessment process, the work of the Global Change Program will, by design, be significant. With stakeholder input, the program targets areas for research that have scientific merit and that people care about.

Relevance — Is the Global Change Program providing useful and useable information and data?

Research findings are relevant only if they respond to the stated needs of end-users and are presented in an understandable, timely manner. Achieving and maintaining relevance is a central goal of the Program's research and assessment activities and of information management within the Program.

Credibility — Are the Global Change Program's research and assessment activities of the highest quality?

Stakeholders and the larger scientific community are the judge. The Global Change Program's research and assessment activities undergo rigorous peer review. The Program is committed to upholding Agency-wide peer review policies (EPA 1998b).

Timeliness — Is the Global Change Program addressing long-term issues with adequate preparation and fulfilling assessment and research objectives in a timely manner?

The optimal timing for research or assessment activities is not always apparent; nonetheless, the Global Change Program has an obligation to work to identify and pursue timely topics. By soliciting input from stakeholders, the Program is assured that the topics addressed are important to end-users now. In addition, the Program strives to respond to customer inquiries and to release products in a timely manner.

ASSESSMENT ORIENTATION

The Assessment Process

Assessment is a scientific process of analysis, review, and synthesis that brings together different groups of people with common interests to address environmental concerns. The assessment process ensures that researchers and decision makers understand what issues are of greatest concern to stakeholders, and that stakeholders understand the scientific basis for resource planning decisions. For example, if stakeholders express concern about an increase in the spread of vector-borne disease as a result of climate change, an assessor might integrate research on climate change, precipitation change, vegetation, rodent population, and the spread of disease to determine if a warmer climate may lead to a greater risk. Results of such an assessment could provide the scientific information needed by public health officials and affected communities.

Assessment of global change is an iterative, analytic process. Analysts and stakeholders are engaged in evaluating and interpreting the interactions of dynamic physical, biological, and social systems. Useful insights about the significant causes and likely consequences of global change are communicated to end-users concerned with resource policy and management. The assessment process and its dynamic interactions with other aspects of the Global Change Program is illustrated in Figure 1.

Assessment consists of three principal elements: problem formulation, analysis, and characterization of consequences. The *problem formulation* phase includes identification of issues of concern, synthesis of existing information, selection of assessment endpoints, identification of scientific relationships and/or models that can be used to estimate consequences, and identification of important information gaps.
In the second phase of assessment — the *analysis phase* — data are evaluated to determine what global changes are likely to occur and what the potential effects may be. For example, data on past and current weather patterns, water quality, and water-borne disease incidence can be used to project how changes in precipitation might affect water quality and human health. The strengths and limitations of available data and models are examined and uncertainties are evaluated. Where information is insufficient or unavailable, proxies may be used. Remaining uncertainties are evaluated and additional research needs may be identified.

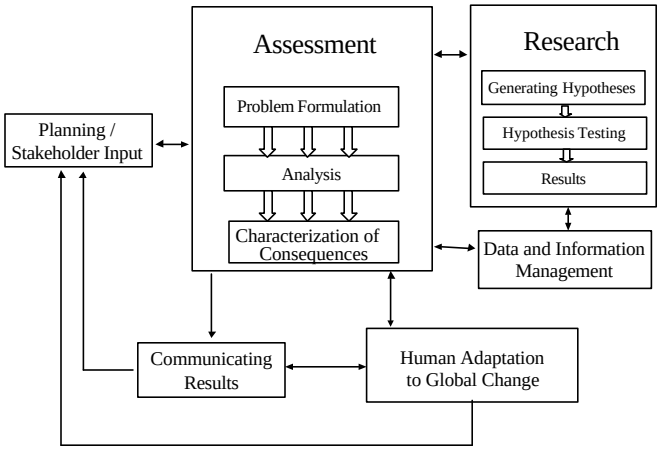

Figure 1. The assessment process with complementary research component envisioned by the Global Change Program (adapted from ORD's Ecological Risk Assessment Framework, 1998).

Since global change is likely to affect many systems simultaneously, the third phase of assessment — *characterizing consequences* — involves integrating global change data (e.g., climate scenarios), models of stressor-response relationships, and other environmental and social data that have a bearing on estimates of potential effects (e.g., air pollutant emission inventories, population growth and demographic data, or economic data). Ultimately the characterization of consequences involves integration across multiple categories of endpoints (e.g., health, ecological, air quality, water quality, and economic). Tools must be developed that allow integration of different types of models, different types of data, and different temporal and spatial scales. In addition, human responses to global change need to be evaluated and incorporated in the assessment.

Stakeholder Involvement

Throughout the assessment process, stakeholder involvement is crucial to ensure that the assessment is relevant and that results are communicated

effectively. Open and well-designed stakeholder participation can increase the credibility of the assessment effort and build public support. In addition, inclusion of stakeholders in the assessment process promotes understanding of and interest in the assessment findings.

Both the public and private sectors need to address global change. Scientists, assessors, decision makers and other interested parties are all stakeholders. They must collaborate from the earliest stages of the assessment process to identify key data and knowledge gaps and to assist in the development of research agendas. This collaboration helps to ensure the policy relevance of the assessment results. In addition, stakeholders may provide information and expertise. By capitalizing on these partnerships, the assessment can be designed to address questions of concern, while helping stakeholders to understand how uncertainties in the environmental, economic, and social systems relate to the uncertainties faced by decision makers. The Global Change Program will hold stakeholder workshops to assist in identifying and prioritizing issues and concerns and to establish conceptual frameworks for conducting assessments.

The Relationship Between Assessment and Research

Assessment and research are viewed as *complementary* activities in the Global Change Program. The research program is guided by the assessment activities and, in turn, provides a steady flow of new scientific and socioeconomic information necessary for conducting assessments. This ongoing, iterative process of research and assessment ensures that the Program addresses relevant topics in a timely manner while remaining responsive to stakeholder needs. Research to support assessments will be provided through the intramural efforts in ORD labs and centers and by extramural funding of STAR grants (see discussion in the Program Capabilities section).

Strategic Principles

The following strategic principles guide the Global Change Program's research and assessment activities.

- *Focus on Future Stresses and the Dynamics of Change.* The Global Change Program is unique among ORD's research activities in that it's goal is not to study current conditions and processes, but rather to build upon ongoing research by examining how possible future changes may influence areas of importance to the public. ORD's air, water, ecosystems, and human health research programs provide monitoring, modeling, and process information that the Global Change Program can use to develop scenarios of the possible impacts of changes in climate and land-use on human health, ecosystems, and socio-economic well-being in the United States.

- *Focus on Both Risks and Opportunities.* Global change will pose both risks and opportunities to society. The Program will identify and assess both adverse and beneficial aspects of global change, in order to help decision makers maximize social well-being.

- *Focus on Multiple Stresses*. Changes in climate, climate variability, land use, and UV radiation are projected to occur in the context of other stresses. For instance, pollution of the nation's air and water and invasion of ecosystems by harmful nonindigenous species are associated with a variety of adverse ecological, economic, and human health effects. The Earth's ecological, socioeconomic, and climate systems are closely linked. To understand the consequences of future global changes, assessments must consider multiple stresses on multiple systems and across multiple species that share interactive and interdependent relationships. Assessments also must consider the various scales over which stressors and species interact and the many endpoints that are of concern to human society. Assessments that do not account for interactive effects may provide inadequate or inaccurate information for developing adaptive responses and may increase the likelihood that ineffective or maladaptive strategies will be adopted.

- *Human Dimensions Considerations.* Human dimensions encompass "analysis of the human causes of global environmental transformations, the consequences of such

changes for societies and economies, and the ways in which people and institutions respond to the changes. They also involve the broader social, political, and economic processes and institutions that frame human interactions with the environment and influence human behavior and decisions" (NRC 1999, p. 295). Research on the environmental effects of human activities is critical for understanding global change. The National Academy of Science's *Pathways* report (1998) and the IPCC have both affirmed that understanding how global change affects and is affected by human society is a crucial element of assessment. The Global Change Program incorporates considerations of human dimensions in both its assessment activities and its research program.

- *Assessment of Adaptation Options (including Potential Multiple Benefits).* Adaptive actions involve adjusting practices, processes, or structures of systems to reduce damages or to take advantage of potential benefits of global change. Adaptation responses may be made in reaction to global change as it occurs or in anticipation of future global change. The assessment of adaptation options is an essential component of global change assessment. Such assessments inform policy and management decisions by improving our understanding of the consequences of global change. The design of effective adaptation measures requires characterization of potential impacts across different populations and geographic regions, and depends on the mechanisms by which the impacts occur. Adaptation strategies need to be evaluated for their effectiveness as well as for any ancillary impacts..

- *Appropriate Geographic Scale*. Perturbations of physical systems associated with global change vary geographically. For example, general circulation model projections show a wide range of changes in temperature and precipitation at regional levels. The resulting impacts on air and water quality, ecosystems, and human health also vary depending on the amount of change in a particular location, the sensitivity of systems to those changes, and the opportunities for adaptation. Many impacts can only be understood at regional or subregional (e.g., watersheds) scales. Since vulnerability to global change differs from place to place, research and assessment activities must utilize appropriate geographic scales. To realize the overall goal — an assessment of the consequences of global change for the U.S. — the Global Change Program will coordinate and aggregate multiple research and assessment activities from a variety of geographic areas and scales.

PROGRAM FOCUS AREAS

INTRODUCTION AND CRITERIA FOR PRIORITIZING

The primary emphasis of EPA's activities will be on those areas in which it has a comparative advantage relative to other agencies conducting global change research. In coordination with other USGCRP agencies, EPA has decided to focus its work in four areas: the effects of global change on human health, air quality, water quality, and ecosystems. ORD's Global Change Program will be able to build upon a strong research foundation in each of the focus areas to anticipate future opportunities or risks.

The four focus areas are interdependent. For example, changes in air or water quality may have important implications for human health. Changes in ecosystems due to climate or land-use change may affect water quality or the spread of infectious diseases. Changes in the frequency or intensity of extreme weather events (e.g., floods, droughts, wildfires) could simultaneously affect public health, air and water quality, and ecosystems. Assessments must capture the interactions between the focus areas.

Several criteria have been identified to help in developing the Program's long-term objectives and to aid in setting priorities for research and assessment. These criteria include:

- *Address the Highest Risks to People and the Environment.* Reduction of global environmental risks is one of EPA's goals (EPA, 1997). Global change also is identified in the *1997 Update to ORD's Strategic Plan* as a research area of high importance. In addition, the proposed research areas are consistent with recommendations in the IPCC Assessments and from the USGCRP.

- *Make a unique contribution.* It is the mission of EPA to protect human health and to safeguard the natural environment — air, water, and land — upon which life depends (EPA, 1997). Other federal agencies also have responsibility for investigating global environmental change as members of the USGCRP. However, EPA has a unique role that goes beyond resource management to the protection of human health, air quality, water quality, and entire ecosystems from environmental risks.

- *Demonstrate relevance to Internal Policy Community (including adaptation responses).* Emphasis is placed on the expected utility of the research and assessment products for addressing both short- and long-term global change risks. EPA's Offices of the Administrator, Air and Radiation, Water, Pollution Prevention and Toxic Substances, and Policy, Economics, and Innovation as well as EPA Regional Offices are the primary internal clients for these products. Assessments conducted by the Global Change Program should help these clients meet their strategic goal and objectives (USEPA 1997b) by supplying information on the potential consequences of global change on the resources for which they have oversight. In addition to supporting Gloal 6 (Global Risks), assessments will address issues outlined in Strategic Goal 1 (Clean Air), Goal 2 (Clean Water), and Goal 8 (Sound Science). The assessments will also support regulatory requirements of the Clean Air Act and Amendments, the Clean Water Act and Amendments, the Safe Drinking Water Act and Amendments, the Food Quality Protection Act, and the Federal Insecticide, Fungicide, and Rodenticide Act.

- *Demonstrate relevance to the External Policy Community.* External clients include regional, state, and local resource managers, other federal agencies, and other stakeholder communities. The input of these client groups will aid in identifying and prioritizing the Program's research.

- *Demonstrate relevance to the National Assessment process.* The assessment activities of the Global Change Program are designed to be consistent with and provide meaningful input to the USGCRP National Assessments.

Hence, the appropriateness of research and assessment work is judged, in part, by its ability to contribute to the goals of the National Assessment.

- *Develop capabilities to assess impacts.* In order to meet the Program's long-term goal of comprehensively assessing potential consequences of global change to human health and ecosystems, it will be necessary to foster the development of tools and models that capture interactions between global environmental changes, physical and biological processes, and human dimensions.

FOCUS AREA I: HUMAN HEALTH

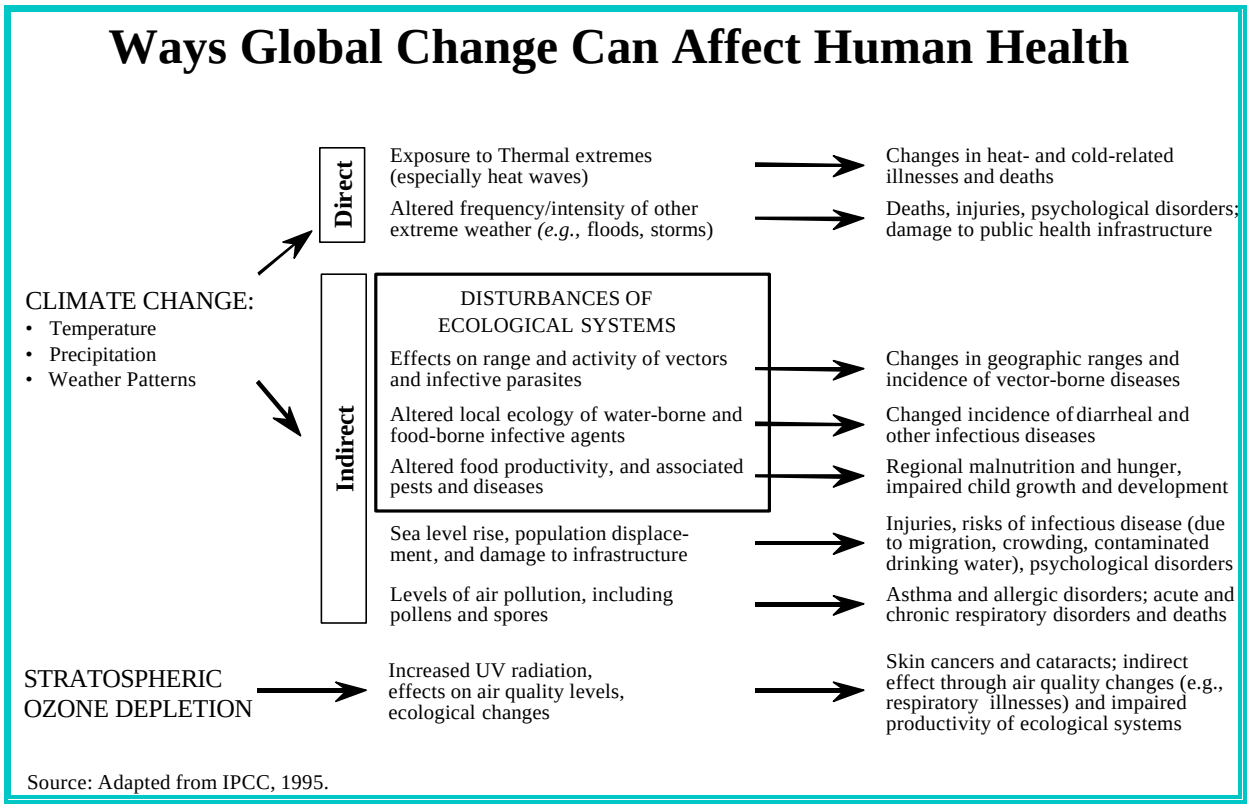

Figure 2. Potential health effects of climate change and stratospheric ozone depletion.

Assessing the Effects of Global Change on Human Health

Health effects associated with global change may be wide-ranging and occur via pathways of varying directness and complexity. A framework for analyzing potential health effects of climate change and UV radiation (see WHO 1996, IPCC 1996a) involves two major categories of effects, direct and indirect (see Figure 2).

Health is affected by a variety of social, political, economic, environmental, and technological factors, including urbanization, affluence (with respect to funds available for research, sanitation, surveillance, and monitoring), scientific developments, and individual behavior. Unanticipated variables can have profound effects on health. For example, in 1997 an avian strain of influenza that had never before infected humans infected and killed previously healthy people in Hong Kong (MMWR 1997; MMWR 1998).

Environmental conditions (e.g., degraded air quality or water contamination) can also affect health status.

Assessing health impacts of global change poses a complex challenge. Global change health impacts take place against a backdrop of continuing changes in demographics, new technologies that pose their own environmental and health risks, and human behavior. Such stresses can affect human health directly or through interactions with global changes. At the same time, improvements in medical care and public health systems moderate outcomes and need to be incorporated in health impact assessments.

Health assessments augment traditional epidemiologic and toxicologic approaches by incorporating impacts of multiple stressors and their interactions. Health assessments under the Global Change Program must integrate information on global changes; other environmental stresses (e.g.,

air and water pollution); ecological and biological processes; social, economic, and political factors; and individual behaviors. Research on relationships between climate change, climate variability, land-use change, long term changes in UV radiation, and health outcomes will be needed to support these assessment efforts.

Assessments also must account for human responses to global change impacts. Adaptive measures — including better management of ecosystems; improved public health monitoring, surveillance, and control programs; disaster preparedness; and the wider use of protective technologies (e.g., sun screen, water purification, and vaccination) — may moderate the effects of global change (WHO 1996, IPCC 1996a). In addition, risks to health from some technological advancements must be considered. For example, increased use of air conditioning protects against heat stress, but may increase emissions of greenhouse gases and conventional air pollutants (e.g., particulates and nitrogen oxides) that have adverse health effects. Similarly, the effects of pesticides on human health, insect predators, and increased insect resistance need to be evaluated if new pesticides are to be used to control disease vectors. In other cases, adaptation options may yield ancillary benefits.

Relatively little research is available to enable quantitative descriptions of probable health impacts associated with global change. There are even fewer integrated assessment frameworks to allow simultaneous evaluation of several stresses (e.g., climate change and land-use change) and account for adaptive responses. The Global Change Program's research and assessment activities will focus on the following analyses of potential health impacts associated with global change (see also Table 4):

- Assessment of the consequences of climate change and climate variability on human health and subsequent assessments of the impacts of global change on human health: USGCRP First (FY2000), Second (FY2004), and Third (FY2008) National Assessments;
- Assessment of potential consequences of climate change and variability on weather-related morbidity (FY2003);
- Assessment of potential consequences of global change (including climate change and variability and land-use changes) on water- and vector-borne diseases (FY2005);
- Assessment of potential health consequences of changes in tropospheric ozone due to global change (FY2007); and
- Assessment of potential health consequences of changes in particulate matter due to global change (FY2009).

The Global Change Program does not plan to conduct assessments of the health effects of long-term changes in UV radiation. The National Institutes of Health through the National Cancer Institute, the National Eye Institute, the National Institute of Arthritis and Muscoloskeletal and Skin Diseases, and the National Institute of Environmental Health Sciences are conducting studies in this area (*Our Changing Planet*, 2000, p. 71-72).

The Global Change Program's health assessments suport EPA's overarching mission to protect human health. In particular, each assessment supports both Goal 6: *Reduction of Global and Cross-Border Environmental Risks* and Goal 8: *Sound Science, Improved Understanding of Envrironmental Risk, and Greater Innovation to Address Environmental Problems*. In addition, the health assessments of tropospheric ozone and particulate matter changes associated with global change are relevant to Goal 1: *Clean Air.* Information from the Global Change Program will also support EPA's Office of Air and Radiation, both in fulfilling their responsibilities under the Clean Air Act and in support of their climate change activities.

The planned health assessments will directly and indirectly support the National Assessment process. The Health Sector Assessment from the first National Assessment identified several research needs which have been used to guide the selection of the health impacts EPA will study. Future assessments will examine the potential effects of global change, including climate change and variability, on the health of the U.S. population during the 21st century. The uncertainties surrounding many variables, including population growth, future economic conditions, other possible changes in health or society (e.g., an epidemic or

war), and the complexities of human behavior, will be addressed. These assessments will be conducted as public-private partnerships involving a range of government, academic, and private institutions (see www.nacc.usgcrp.gov /sectors/health).

Other factors that guided the development of the *Strategy* include whether other USGCRP agencies are conducting research and assessments on a particular health endpoint (e.g., the exclusion of UV health effects work due to NIH's involvement in UV research), unique EPA capabilities (e.g., in assessing health endpoints associated with air pollution), and past EPA experience (e.g., with research on weather-related mortality).

Weather-related Morbidity

Some preliminary analyses of weather-related mortality have been conducted (EPA 1989, WHO 1996, Kalkstein and Greene 1997). While our understanding of certain issues associated with future weather-related mortality remains poor (e.g., the degree to which people can acclimatize to increased warmth, how much of increased temperature-related mortality is mortality displacement [the shortening of a human life by only a few days], and the balance between heat- and cold-related mortality) there are even fewer studies focused on climate change and heat-related morbidity. A number of heat-related morbidity effects need to be investigated, including: heat-related symptoms that do not require a visit to a medical provider (e.g., heat nausea, heat cramps, headache, heat fainting) and emergency room visits or hospital admissions for heat-related illnesses.

The direct effect of weather on public health goes beyond extreme temperatures. Climate change could also affect precipitation (rain and snowfall), precipitation intensity (flash flooding), and extreme events such as storms and hurricanes. Land use changes, such as increased urbanization in floodplains and coastal areas, could exacerbate vulnerability to these climatic changes. Potential health effects from inclement weather include deaths, injuries, and illnesses. For example, blizzards and snowfalls have been associated with increased mortality (Glass and Zack 1979; Gorjanc *et al.* 1999). Secondary health effects resulting from economic losses and natural resource devestation in the aftermath of extreme weather events could also be significant and are largely unexplored.

Water- and Vector-borne Diseases

An assessment of water- and vector-borne diseases is expected to be conducted from FY 2002 through FY 2005. These activities will build on a concurrent Water Quality assessment on pollutants and microbial pathogens.

Water-borne Diseases. An assessment of water-borne diseases will focus on two topics: 1) water-borne diseases spread through contaminated drinking water or recreational water; and 2) coastal/marine health issues, including harmful algal blooms. There are many determinants of these types of diseases, such as poor sanitation, poor erosion control, application of agricultural fertilizers, and coastal sewage release. In addition, many cases of water-borne diseases go unreported. This contributes to the lack of understanding of the full extent of the problems caused by contaminated water sources. Nonetheless, water contamination appears to be an important environmental risk (EPA 1990) and poses a risk management challenge for drinking water suppliers (EPA 1998a).

Global change may further exacerbate the health risks associated with these factors through more intense precipitation events, more droughts, and increased water temperature. Both increases in flooding and water shortages can impair local sewerage, degrade water quality, and alter the potential risks of diarrheal and dysentery epidemics. Several environmental factors including sunlight, pH, ocean currents, winds, sea surface temperatures, and nutrients can influence algal production (Valiela 1984; Epstein *et al.* 1993). Algal blooms can influence the transmission of some bacterial diseases such as *V. vulnificus* and *V. parahemolyticus*. Algal blooms also are associated with biotoxin contamination of fish and shellfish. Increases in UV radiation also can alter microbial and viral activity in aquatic ecosystems (Herndl *et al.* 1997, Zepp *et al.* 1998).

Vector-borne Diseases. There is an extensive literature on the relationship between meteorological variables, especially temperature,

and various aspects of vector-borne disease transmission (e.g., parasite development, biting behavior, reproduction rates, bioclimatological thresholds). These relationships have been summarized in several review articles and book chapters (Patz *et al.* 1996, WHO 1996). There also have been some efforts to develop integrated systems-based models that include: theoretical constructs that describe the various components in the system, relationships between these components (e.g., vectorial capacity), and the best available information from field and laboratory studies that can be used to estimate parameters describing these relationships. With a few exceptions, existing models have not been linked to global changes, such as climate scenarios from General Circulation Models (GCMs). Even fewer models include human dimensions or explicitly consider costs and the implications of medical interventions.

Air Pollution-related Health Effects

Global change may affect exposures to air pollutants by affecting: 1) weather, and thereby local and regional pollution concentrations; 2) UV radiation, and thereby local and regional pollution concentrations, especially tropospheric ozone; 3) anthropogenic emissions through adaptations involving increased fuel combustion for power generation; and 4) biogenic emissions. In addition, global change may increase or decrease the amount of time individuals spend indoors, resulting in changed exposure to indoor pollutants and allergens that are, in some cases, more hazardous than ambient conditions. Changes in air pollutant concentrations are discussed more fully in the third focus area, Air Quality. Assessment activities in the Air Quality focus area will provide baseline information about ozone and particulate matter under conditions of global change that will be used to derive health effects estimates.

The substantial body of scientific literature relating air pollution to health effects has been discussed elsewhere (see for example: www.epa.gov/ncea/partmatt.htm and www.epa.gov/ncea/ozone.htm). In assessments of the health impacts associated with global change-induced changes in air pollution levels, the Global Change Program will rely on this literature and on ORD expertise.

Additional Considerations

As noted above, various adaptive responses at the societal or individual level, could substantially reduce the impacts of global change on human health. Many of these responses are simply an intensification or enhancement of ongoing public health programs. In other cases, application of existing protective technologies can reduce health impacts (e.g., air conditioning, sanitation, water purification). Human responses to health risks posed by global change will be included in the research and assessments described above. The effectiveness and costs associated with adaptive measures will be evaluated along with the potential co-benefits or maladaptations that may accompany various adaptation strategies.

Making the Connection — from Adaptation Research to Assessment

Human responses to global change must be accounted for in assessments of health impacts. ORD researchers are in the process of identifying approaches (both technological and socioeconomic). In particular, technologies implemented for one environmental problem may impact (positively or negatively) other environmental stressors. Researchers are examining these "ancillary" effects. This research will contribute to the Global Change Program's ability to accurately assess the effects of global change on human health.

Table 4. Focus Area I: Human Health

Research Questions (see related Assessment Component in next column)	Assessment Components (Fiscal Year Due Date)
Assessment of Weather-Related Morbidity	
What is the quantitative relationship between heat stress and cold stress and various illnesses, particularly in vulnerable populations? (1,2,5) How will the incidence of these illnesses change as the earth warms? (1,2,5) How are temperature-related illnesses modified by personal characteristics and behaviors? (1,2,5) How are changes in weather patterns (e.g., inclement weather, snowfall, storms) associated with morbidity, including injuries and other public health outcomes? (3,4,5)	1. Evaluate heat and cold morbidity in children (2003) • review and summarize literature and identify existing data • where possible, statistically analyze the relationship between morbidity and temperature extremes 2. Statistically analyze the association of ER and hospital admissions for heat-related illnesses with variations in temperature and humidity and socio-demographic characteristics (2003) 3. Statistically analyze the relationship between inclement weather and accidental injury, especially injuries caused by motor vehicle accidents (2003) 4. Examine existing literature and conduct preliminary analysis of existing data on the relationship of public health concerns, such as violent crime, to weather variation (2003) 5. Develop a peer-reviewed assessment report on aspects of weather-related morbidity (2003)
Assessment of Water- and Vector-Borne Disease	
Which water-borne diseases are sensitive to climate and land-use change? (1,2,6) Which aspects of climate and land-use change exert the most important effects on water-borne disease risks? (1,2,6) Based on what we know about potential changes in the hydrological cycle, water temperatures, frequency of extreme conditions, sea-level rise, and land-use changes, how are water-borne disease risks likely to be affected? (1,2,6) Based on what we know about changes in climate and land use, how are habitats of disease-carrying vectors (terrestrial, freshwater, marine) likely to be altered? (3,6) How can existing models be utilized to estimate potential changes in future disease risks? (3,6) How effective and costly are adaptive measures designed to manage adverse health impacts associated with water and vector-borne diseases? (3,6) How do allergic responses to flora and fauna vary with changes in climatic conditions? (4,6) How is the quality of life impacted by variations in vector populations mediated by changes in climate or land-use? (5,6)	1. Conduct a workshop to establish a research agenda for the study of water-borne disease risk under climate and land-use change (2005) 2. Assess water-borne disease risk under climate and land-use change (2005) < review and summarize literature < adapt existing models to estimate effects 3. Assess climate and land use-related vector-borne disease risk, adaptation potential, and economic valuation of risk (2005) < review and summarize literature < adapt existing models to estimate effects 4. Analyze climate-related variation in allergic reactions to flora and fauna (2005) 5. Examine quality of life effects associated with vector prevalence related to climate variability and land-use change (2005) 6. Develop a peer-reviewed assessment report on water- and vector-borne diseases under global change (2005)

Assessment of Ozone Health Effects under Global Change	
How do changes in climatic conditions and changes in anthropogenic and biogenic emissions associated with climate and land-use change affect human exposures to tropospheric ozone? (1,3) What health effects are associated with ozone exposures mediated by climate and land-use changes? (2,3) How would societal changes and technology advancements adopted either to respond to climate change or reduce harmful ambient levels of tropospheric ozone affect health risks and what combinations of these human adaptive responses would provide the greatest combined risk reduction (co-benefits) at the lowest cost? (3)	1. Utilizing existing literature and models, assess climate and land-use change impacts on human tropospheric ozone exposures (2007) 2. Apply human dose-response estimates for ozone in Section 812 Health Benefits Model to estimate health effects (2007) 3. Develop a peer-reviewed assessment, accounting for human adaptation, to report on ozone health effects under global change (2007)
Assessment of Particulate Matter Health Effects under Global Change	
How do changes in climatic conditions and changes in anthropogenic and biogenic emissions associated with climate and land-use change affect human exposures to particulate matter? (1,3) What health effects are associated with particulate matter exposures mediated by climate and land-use changes? (2,3) How would societal changes and technology advancements adopted either to respond to climate change or reduce harmful ambient levels of particulate matter affect health risks and what combinations of these human adaptive responses would provide the greatest combined risk reduction (co-benefits) at the lowest cost? (3)	1. Utilizing existing literature and models, assess climate and land-use change impacts on human particulate matter exposures (2009) 2. Apply human dose-response estimates for particulate matter in Section 812 Health Benefits Model to estimate health effects (2009) 3. Develop a peer-reviewed assessment, accounting for human adaptation, to report on particulate matter health effects under global change (2009)

FOCUS AREA II: ECOSYSTEMS

Assessing the effects of global change on ecosystems

EPA's mission is not only to protect human health but to safeguard the natural environment. EPA has pledged to provide environmental protection that "contributes to making communities and ecosystems diverse, sustainable and economically productive" (EPA 1997). This pledge requires EPA to think comprehensively about entire ecological systems. Therefore, a priority of the Global Change Research Program is to conduct assessments of the effects of global change on ecosystems in the context of other stressors and human dimensions in order to improve society's ability to respond to the future consequences of global change.

Changes in the climate system, in human behavior, and in human demands on ecosystems will continue to occur, necessitating the development of predictive conceptual models to assess future ecosystem status that incorporate multiple stressors. For each research and assessment activity outlined below, the Global Change Program will examine the future consequences of global change on dominant physical aspects of ecosystems and/or on key species within the ecosystem type, how these changes will affect ecosystem functioning and the services provided, and potential adaptation measures. The primary focus of ecosystem assessment activities will be on aquatic ecosystems, in keeping with the long-standing emphasis of EPA's ecosystem work. The Global Change Program's assessment and research activities are focused on three areas:

- Assessing the consequences of global change for aquatic ecosystems (2004);
- Assessing the consequences of global change for nonindigenous invasive species (2006);
- Assessing the consequences of global change for ecosystem services (2009).

These three assessments are related to each other and also to the two Water Quality assessments. In addition, each ecosystem assessment supports multiple EPA strategic goals, including: Goal 2: Clean and Safe Water, Goal 6: Global Risks, and Goal 8: Sound Science. Likewise, information from the Global Change Program will support the Office of Water in fulfilling their responsibilities under the Clean Water Act and Amendments which calls for restoration and maintenance of the integrity of the Nation's waters, including conservation of waters for the protection and propagation of fish and aquatic life and wildlife, and for recreational purposes.

In addition to supporting EPA Program Offices, the ecosystem assessments will support the ongoing analytic efforts of the USGCRP. In particular, the National Assessment's Water Sector assessment calls for the development of models linking climate variability and ecological processes and for integrated assessments of the potential impacts and response options related to alternative future climates (Meyer *et al.* 1999).

Aquatic Ecosystems

Aquatic ecosystems (i.e., streams, rivers, lakes, wetlands, and estuaries) are sensitive to changes in climate, climate variability, land use, and UV radiation. Changes in climate and climate variability will affect precipitation patterns (the timing, form, and seasonality of precipitation; and the frequency and intensity of precipitation events) and evapotranspiration rates (which are temperature dependent). Climate change and variability will also affect aquatic ecosystems via increased concentrations of carbon dioxide, increased air and water temperatures, sea level rise, storm surges, changes in streamflow to the coast, altered pollution loads, and salinity changes in coastal ecosystems.

UV radiation affects plants, microbes and animals directly, and indirect ecosystem effects are mediated by changes in plant composition, microbial populations, secondary chemistry, plant litter decomposition, and air quality (Caldwell *et al.* 1998). In addition to short-term effects, the impacts of elevated UV radiation on natural systems will include shifts in species that may alter ecosystem functioning and productivity (Herndl *et al.* 1997, Karentz *et al.* 1994, Lindell *et al.* 1995, Rozema *et al.* 1997, Wetzel *et al.* 1995, Zepp *et al.* 1998).

Land-use change, considered to be the most pervasive human cause of loss of biodiversity, is leading to habitat destruction through conversion from one habitat type to another or through modification of conditions within a habitat type. Changes in sediments, nutrients, toxics, and nonindigenous species are examples of the multiple stressors that shape the context in which land use and climatic changes are occurring. Climate variability, including extreme events like hurricanes, droughts, and floods will also affect ecosystem functioning. Droughts that lead to intermittent flows and drying of streambeds for extended periods reduce ecosystem productivity as aquatic habitat is restricted, water quality is reduced, and intense competition and predation reduce total biomass (IPCC WGII 1996).

Making the Connection — from Ecosystem Research to Assessment

Changes in stream flow and thermal regimes are likely to have significant effects on the composition of fish communities. ORD researchers are engaged in creating a nationwide fish-temperature-flow matched dataset and developing empirical relationships between flow and thermal regime metrics and fish species presence. This research will directly contribute to the Global Change Program's ability to assess the effects of global change on aquatic ecosystems.

The impact of global changes on aquatic ecosystems and their functioning is recognized as an important area for research and assessment because of the goods and services they supply (Daily 1997; National Assessment Synthesis Team 2000) and because these systems may be significantly affected by global change (National Assessment Synthesis Team 2000; Pathways 1999). In particular, the effects of climate change and variability on aquatic ecosystems is as an important research area because our understanding of how these stressors affect the physical, chemical, and biological characteristics of aquatic ecosystems is limited (Meyer, *et al.*; IPCC 1996). More extensive data sets and better models are needed that link hydrologic regimes with ecosystem processes, with ecological interactions and with water quality.

With a focus on selected river basins, this assessment will adopt a taxonomy for understanding and expressing the changes that aquatic ecosystems may undergo due to changes in climate and climate variability, land use, and UV radiation. Where possible, the taxonomy of ecosystem services will be used to express assessment results. The term "ecosystem services" describes both the conditions and the processes through which ecosystems sustain and fulfill human life. Ecosystem services maintain biodiversity, produce goods, and perform life-support functions. People are generally willing to invest resources to protect things they know they value. Natural systems are sometimes undervalued because their importance to society is often not well understood by the public. Using ecosystem services as assessment endpoints provides a means to articulate how global changes will affect aquatic ecosystems, and the implications of those changes for society.

Using this approach, an overview of the effects of global changes on ecosystem services for different aquatic ecosystem types will be developed, based on expert opinion and a review of the literature. Similar aggregate assessments have been done of the impacts of climate change on aquatic ecosystems for physiographic regions in the U.S., but they have not used ecosystem services as assessment endpoints (see Meyer *et al.* for an overview of these studies).

Next, smaller-scale studies (case studies), will be conducted to build on insights gained from the larger scale assessment. These studies will employ the ecosystem services framework developed by this program for assessments of global changes at the scale of watersheds. This framework will provide guidance for identifying *a priori* the types of services most likely to be affected by various stressors (climate change, land-use change, UV radiation), and methods for measuring, modeling, or estimating the ecosystem services impacts at specific sites.

The locations for the case studies will represent diverse geographic regions and aquatic ecosystem types, different land-use pressures (e.g., agricultural pressures, urban growth pressures), and different future climate-induced changes (e.g.,

increased versus decreased runoff). These sites will be chosen because of their highly-valued ecosystem services (e.g., recreational activities such as birding and fishing or irrigation), and the amount of available data and existing research on which our program can build. The results of this assessment will have direct applicability to the regional assessments and the water sector assessment within the National Assessment, and to the fourth assessment report of the IPCC. Existing stakeholder contacts and processes developed through the National Assessment will be tapped for information and collaboration during the conduct of the site-specific case studies.

Table 5 outlines the research questions that will guide the assessment and the components necessary to complete the aquatic ecosystems assessment. These components map directly into capabilities of the labs and centers and those of the extramural grants program (see Program Capabilities section). The assessment report will include a conceptual model (see Glossary) that describes predicted relationships among global change, resultant stressors on aquatic ecosystems, exposure, and the response of aquatic ecosystem endpoints. The idea of ecosystem services will be used to guide the selection of aquatic ecosystem endpoints.

Nonindigenous Invasive Species

Harmful non-indigenous species (NIS) are responsible for a variety of deleterious effects, including the decline of many indigenous species (even contributing to the extinction of some species), the transformation of ecological communities and ecosystems (e.g., by altering processes such as primary productivity, decomposition, hydrology, geomorphology, nutrient cycling, and/or disturbance regimes), and the reduction of global biodiversity (OTA 1993, Vitousek *et al.* 1996, Vitousek *et al.* 1997). Pimental *et al.* (2000) estimate that nonindigenous species cost the United States over $137 billion annually in losses to agriculture, forestry, fisheries, water use, utilities, buildings, and natural areas. Climate change could accelerate losses of threatened or endangered native species while failing to exert the same negative pressure on harmful nonindigenous species, possibly exacerbating current problems (Dukes *et al.* 1999).

Many federal government agencies and academic institutions are actively engaged in research on invasive species. Yet, this stressor has not been widely considered in current research plans (Our Changing Planet 2000). The Executive Order on Invasive Species (E.O. 13112) established an interagency National Invasive Species Council that is required to develop an invasive species Management Plan. Some of the member agencies and academic institutions involved include the Smithsonian Institution, USDA, USGS, NOAA, DOD, NSF, DOC, DOI, EPA, APHIS, FAS, and the Association of Systematics Collections. As part of the Management Plan, ORD is collaborating with NOAA and the states of California, Oregon, Washington, Hawaii, and Alaska to run a monitoring program (Western EMAP) that will survey the nonindigenous benthos and fishes of the coastal ecosystems of the West Coast. This program will generate estimates of the extent and nature of invasions along the entire coast. EPA is also participating in the Delaware Basin Invasive Species Monitoring Program, a program that will develop monitoring systems for invasive plants, insects, and pathogens integrated with forest health and water quality monitoring in the Delaware River basin.

To capitalize on these planned outputs, the Global Change Research Program will leverage limited resources to examine the additional effects of climate change on nonindigenous species based on the existing literature (Table 5). This effort is consistent with the FY 2000 priorities of the USGCRP who list among their areas of focus the development of "methods that assess the invasiveness of nonindigenous species by combining the science of landscape ecology with the principles of risk assessment" (Our Changing Planet 2000). Insights gained from this effort will be shared with other agencies engaged in NIS research. In addition, the results of this assessment will have direct applicability to the USGCRP regional assessments and to the IPCC.

Ecosystem Services

The ecosystem services assessment will extend the aquatic ecosystems assessment by incorporating more quantitative approaches and indices, especially biocriteria. States use biocriteria programs to evaluate the status of aquatic ecosystems, to diagnose threats, and to develop strategies for protecting aquatic ecosystems. Some of the biological indicators that are used in biocriteria programs may be useful indicators of ecosystem services. By 2008, the Global Change Program will have provided states with a framework to evaluate whether global change will impair their ability to meet biocriteria standards and to identify adaptation options to help them cope with global change (see Water Quality biocriteria assessment).

For this assessment of ecosystem services, the Global Change Program will partner with states to develop tools to evaluate the vulnerability of aquatic ecosystem services, to identify adaptation options, and to incorporate ecosystem services into biocriteria or other state programs. The components that are necessary for this assessment are described in Table 5. These components build on previous assessments (aquatic ecosystems described above and Water Quality assessments of pollutants and pathogens and of biocriteria).

Linking biocriteria and the production of ecosystem services could strengthen state biocriteria programs by articulating how stressors (including those induced by global change) affect the conditions and processes through which aquatic ecosystems sustain and fulfill human life. This may help policymakers and the general public to evaluate and prioritize actions needed to protect aquatic ecosystems. The goal of this assessment is consistent with the NRC's Science Priorities for the Human Dimensions of Global Change (NRC 1994), the USGCRP's Our Changing Planet (FY 2000) and the National Assessment process.

Table 5. Focus Area II: Ecosystems

Research Questions (see related Assessment Component in next column)	Assessment Components (Fiscal Year Due Date)
Assessment of Aquatic Ecosystems	
How should aquatic ecosystem types and ecosystem services be classified to facilitate analysis? (1)	1. Establish taxonomy of aquatic ecosystem types and services for purposes of assessment. (2001)
What is a useful framework to apply to assess the impacts of global change on aquatic ecosystem services? (2)	2. Develop ecosystem services framework to apply to aquatic ecosystem assessments at the scale of river basins. (2001)
How are different aquatic ecosystem types potentially vulnerable to future changes in climate and climate variability? (3) What are the problems that arise because of extrapolation from individual studies to conclusions about effects on ecosystem types? (3) What are the other major sources of uncertainty (e.g., in climate science, in ecological modeling)? (3)	3. Use methods of eliciting scientific expert opinion to conduct qualitative assessment of climate change and variability effects on aquatic ecosystems by ecosystem type. (FY2003) • Articulate from the existing literature a conceptual model (see Glossary) of the effects of climate variability and change on aquatic ecosystems. Include literature from pollutants and pathogens assessment as it becomes available. • Write a paper that draws conclusions about potential effects of climate variability and change on aquatic ecosystem services for each ecosystem type, and identifies uncertainties, research needs and methodological issues. • Convene a workshop of experts to review the paper and develop a consensus on the paper's conclusions.
How are different aquatic ecosystem types potentially vulnerable to future changes in UV radiation? (4)	4. Utilizing the work of ORD labs, grantees, and the existing literature, produce a document that synthesizes the literature/studies (and articulates a conceptual model) on the potential future effects of UV radiation on aquatic ecosystems by ecosystem type. (2003)
How are different aquatic ecosystem types potentially vulnerable to future changes in land use? (5)	5. Utilizing the work of ORD labs, grantees, and the existing literature, produce a document that synthesizes the literature/studies (and articulates a conceptual model) on the potential effects of future land use on aquatic ecosystems by ecosystem type. Include information from pollutants and pathogens assessment as it becomes available. (2003)
How can geographically-specific, quantitative analyses improve our understanding of the vulnerability of specific aquatic ecosystem types? What can we learn by examining the relationships among aquatic ecosystem types within a river basin, the interactions of multiple stressors, and the adaptation strategies that are available to stakeholders in a specific region? (6)	6. Perform 3 in-depth case studies and draw from the EPA-sponsored regional assessments to quantitatively estimate the effects of climate, land-use change, and UV radiation on different types of aquatic ecosystems. (2004) • Draw on other federal agencies and research institutions to obtain regionally specific climate change scenarios • Develop or obtain regionally or locally specific land-use change scenarios • Adapt linked hydrologic and ecological models • Refine existing sea level rise models • Adapt existing, regionally specific vegetation models • Estimate future climate, land-use, and UV radiation effects on water quantity, water quality, aquatic habitat quality and extent, ecosystem services • Examine adaptation options • Based on results, develop future research priorities
What should we communicate to stakeholders to facilitate their understanding of the vulnerability of aquatic ecosystems, including ecosystem services, to global change and to aid their	7. Write final assessment that synthesizes the results of impacts of climate, land use, and UV radiation on diifferent aquatic ecosystem types. (One product of this assessment is an overarching conceptual model of climate, land-use, and UV

evaluation of adaptation options to protect vulnerable ecosystem services? (7)	effects on aquatic ecosystems.) (2004)
Assessment of Nonindigenous Invasive Species	
How could climate variability and change affect the distribution of nonindigenous species and alter their effects on native species and ecological communities? (1) How might the Global Change Program encourage federal agencies and research institutions to consider the effects of climate variability and change on nonindigenous invasive species? (2)	1. Conduct literature review and write a paper on the effect of climate change and variability on nonindigenous invasive species in preparation for the workshop to be held in FY2006. (2005) 2. Facilitate workshop with other agencies, the IPCC, and academic institutions and prepare a workshop report that summarizes the state of the science and updates the research agenda. (2006)
Assessment of Ecosystem Services	
What tools can states use to aid their evaluation of the vulnerability of aquatic ecosystem services to global change and identify adaptation options to protect aquatic ecosystem services? (1) Could biological indicators that are used for state biocriteria programs be used as indicators of ecosystem services? (1) Can states use their biocriteria programs to monitor the status of and diagnose threats to ecosystem services? (1) Are there other state programs that could be used to assess the vulnerability of aquatic ecosystem services to global change? (1) What strategies are available to states to protect ecosystem services? How can states identify adaptation options to meet biocriteria that relate to ecosystem services, and how can they link these adaptation options to tools they already have (e.g., National Pollutant Discharge Elimination System, Non-point Source Pollution programs, Total Maximum Daily Loads, watershed restoration)? (1) What should we communicate to states, the Office of Water, and other stakeholders to facilitate their assessment of the vulnerability of ecosystem services to global change, and to aid their evaluation of adaptation options? (2)	1. Utilizing the work of ORD labs, the Office of Water, and previous Global Change Program assessments, conduct a study with the Office of Water and selected states to determine what tools states could use to aid their evaluation of the vulnerability of aquatic ecosystem services to global change and identify adaptation options to protect aquatic ecosystem services. (2009) • Drawing on the preceding aquatic ecosystems assessment and the Water Quality assessments (of pollutants and pathogens and of biocriteria), identify indicators of ecosystem services and determine if indicators used in biocriteria programs or other state programs could be used as indicators of ecosystem services. • Construct an updated conceptual model for the effects of global change on aquatic ecosystem services using the results and conceptual models from the aquatic ecosystems assessment and the Water Quality assessments. • Work with the Office of Water and selected states to determine how state biocriteria programs and other state programs could be used to monitor the status of ecosystem services, identify threats (e.g., global change) to ecosystem services, and develop adaptation strategies to protect ecosystem services. 2. Prepare a final report that identifies tools that states can use to assess the vulnerability of their aquatic ecosystem services to global change, to identify adaptation options, and to incorporate ecosystem services into state programs. (2009)

FOCUS AREA III: AIR QUALITY

Assessing the effects of global change on air quality

Air pollution continues to be a widespread public health and environmental problem in the United States. People are constantly exposed to air pollutants, whether indoors or outdoors. The health effects of air pollution range from episodes of increased mortality at high pollutant concentrations to more subtle effects on respiratory health. Air pollution also has been associated with increased use of health care services, including visits to physicians and emergency rooms and admissions to hospitals. Other effects of air pollution include reduced visibility, damage to crops and buildings, and acid deposition on soil and in water bodies where the chemistry of the water and resident aquatic species are affected (USEPA 2000).

Ambient concentrations are largely determined by the air pollutant emissions and the meteorological conditions at the time of pollutant release. Climate change, UV radiation, and land-use change can each influence emissions, meteorological variables, or both. Other factors affecting emissions include population, level of economic activity, structure of the economy, energy demand and generation (fuel use, type, and efficiency), and emission controls.

Few studies have investigated the effects of global change on air quality. Examining the effects of global change on air quality is a major focus of the Global Change Research Program, given EPA's legal mandate with respect to air pollution, the agency's substantial capability and expertise in modeling air quality, EPA regulatory efforts in this area, and the important health effects that have been associated with both tropospheric ozone and particulate matter.

The Global Change Program plans the following two assessments focused on air quality:

- # Assess potential consequences of global change on tropospheric ozone concentrations (FY2004), and
- # Assess potential consequences of global change on particulate matter concentrations (FY2007).

The Global Change Program's air quality assessments directly support EPA's Goal 1: *Clean Air* in addition to Goal 6: *Reduction of Global and Cross-Border Environmnetal Risks* and Goal 8: *Sound Science*. Information from the Global Change Program will also support EPA's Office of Air and Radiation, both in fulfilling their responsibilities under the Clean Air Act and in support of their climate change activities.

The planned assessments will also support the ongoing National Assessment process. In particular, the Health Sector Assessment from the first National Assessment identified as a high priority research area work on determining the relationships between weather and air pollution. Other factors that guide this *Strategy* include examination of global change affected air pollution concentrations and the importance of pollutants in terms of extent, health impacts, Agency policies, and ongoing ORD research efforts and programs.

The goal of the two air quality assessments is to answer the following questions: What is the effect of projected changes in climate, climate variability, UV radiation, and land-use patterns on air quality (specifically ground level ozone and particulate matter)? Which areas will experience the largest deterioration in air quality due to global change? Which areas will experience improvements in air quality due to global change? How many areas will

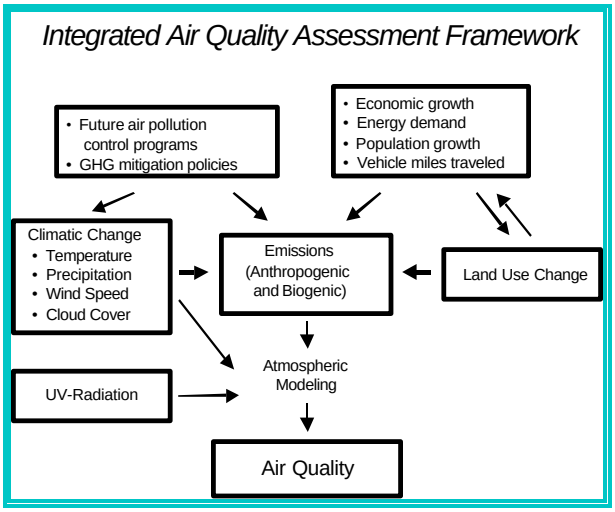

Figure 3. Framework of an Integrated Air Quality Assessment.

fail to attain air quality standards due to global change? Because atmospheric processes can be highly non-linear, the Air Quality assessments will also account for changes in emissions across time and underlying factors driving emissions such as the level of economic activity, energy demand and generation, and emission controls.

Figure 3 illustrates how the effects on air quality of future changes in climate, UV radiation, and land-use will be modeled. A set of meteorological variables needed for air quality simulations will be developed, and the relationships between weather and tropospheric ozone and particulate matter (PM) will be statistically analyzed. Baseline and future emissions scenarios will be developed for ozone and PM using scenarios of economic growth, energy demand, population growth, vehicle miles traveled, policy scenarios, and information about anthropogenic and biogenic emissions. Base case and future concentrations of ozone and PM will be simulated, and peer-reviewed assessment reports will be developed for these two air pollutants. Table 6 lays out the research questions that will guide these assessments and the components necessary to complete the assessments. These components map directly into capabilities of the labs and centers and those of the extramural grants program (see Program Capabilities, p. 10-11).

Global climate change will likely result in changes in regional and local weather, which in turn may affect air pollution levels by altering rates of atmospheric chemical reactions, transport processes, and export of pollutants. Emissions of photochemical oxidant precursors from both anthropogenic and natural sources also are affected by regional and local weather. Warmer temperatures affect energy demand and therefore emissions from fossil fuel-based electric utilities. In addition, evaporative emissions from mobile sources are temperature-sensitive. Studies show that ozone concentrations can be strongly influenced by natural emissions as well (Fehsenfeld et al.1992, Chameides et al. 1988). Temperature and other meteorological variables influence processes related to production, transport, and release of most biogenic gases. Soil temperature and moisture affect emissions from soils.

Making the Connection — from Air Quality Research to Assessment

ORD scientists provide substantial support ito the Agency in computer modeling of pollutant transport and fate. They perform analyses integrating inter-continental transport and global change effects with regional and urban scales found in air quality models. This research will directly contribute to the Global Change Program's ability to assess the effects of global change on air quality.

UV radiation affects chemical activity in the troposphere and can either increase of decrease ambient concentrations of air pollutants (UNEP 1998). Some ozone depleting substances and some of their substitutes are also greenhouse gases and thus can contribute to global climate change. Solar radiation also plays a key role in determining fluxes and leaf temperatures which are determinants of biogenic emissions. Finally, patterns of land-use can influence biogenic and anthropogenic emissions (e.g., increased urban sprawl may result in higher emissions from transportation sources or construction activities that lead to fugitive dust). Simultaneous changes in land-use and climate could affect PM emissions (related to fugitive dust and wildfire frequency) and emissions of volatile organic compounds or VOCs (related to changes in vegetation), important precursors of tropospheric ozone. In addition, human activities can also influence biological emissions (e.g., fertilized agricultural soils tend to have high NOx emissions) (Kinnee *et al.* 1997). Quantitative estimates of the potential magnitude of these combined effects are needed for future assessments.

Existing atmospheric dispersion and transformation models can be used in the assessments. Some have been developed in support of federal clean air programs and state implementation plans (SIPs). These analytical and numerical models describe the transport, dispersion, transformation, and removal of atmospheric pollutants on local, urban, and regional scales. Examples include the Industrial Source Complex Model (ISC3) and the Urban Airshed Model (UAM).

More recently, ORD has developed a third-generation air quality modeling system, Models-3. This modeling system will be able to simulate an atmosphere with various mixes of pollutants up to continental scales and incorporate feedbacks between chemical and meteorological components. This will enable researchers to see how pollutant concentrations are affected by climate changes or how pollutants are transported across large geographic areas.

The "one atmosphere" perspective of ORD's Models-3 is consistent with the ultimate air quality assessment goal of the Global Change Program. However, the Program will not be directly involved in Models-3 development. Instead, the Program anticipates using Models-3 in future assessments of global change impacts (augmented by models of land-use change, energy demand, population growth, climate change, and regulatory scenarios). (For additional information see www.epa.gov/asmdner/models3/.)

More generally, while current global stresses — climate variability, UV radiation, and land-use patterns — are affecting air quality, there are a number of basic scientific questions that must be resolved before the Global Change Program can assess the air quality consequences of global change. Many of these questions are the subject of ongoing EPA research. While the Global Change Program will not directly conduct scientific studies on these questions it will work closely with others in EPA involved in that research and will incorporate new scientific findings in its assessments of the air quality effects of global change.

Adaptation — Potential Human Responses and Co-Benefits

EPA currently has an extensive program to control anthropogenic emissions of ozone precursors. Knowledge of potential global change impacts on ambient concentrations (e.g., through effects on anthropogenic and biogenic emissions, atmospheric transport, and stagnation frequencies) is needed to design effective emissions control strategies. Adaptive responses to global change will likely involve continuation and possibly enhancement of ongoing emission reduction efforts. However, it will be necessary to evaluate potentially adverse consequences of adaptation strategies. For example, a strategy to reduce emissions from a coal-fired power plant may involve building a new gas pipeline through a sensitive ecosystem. Impacts on the ecosystem should be considered when evaluating this adaptive response.

In addition, there have been few studies of the impact of policies and new technologies to reduce greenhouse gas emissions on concentrations of criteria air pollutants. As fossil fuel combustion is a major source of both types of emissions, control programs and new technologies can be expected to yield substantial co-benefits. For example, in a study examining the impact of a climate policy on particulate emissions, major reductions in particulate air pollution were realized (developed countries reduce CO_2 emissions to 15% below 1990 levels, developing countries reduce CO_2 emissions to 10% below forecasted 2010 levels) (Working Group on Public Health and Fossil-Fuel Combustion, 1997). While this study relied on a number of assumptions, the results can be viewed as illustrative of the potential magnitude of the co-control benefits of mitigation policies. Future assessments in the Global Change Program will rely, to the extent possible, on state-of-the-art air quality models. EPA also plans to conduct the research to support assessments of co-benefits (e.g., the development of databases of criteria pollutants and GHG emissions from alternative technologies).

Table 6. Focus Area III: Air Quality

Research Questions (see related Assessment Component in next column)	Assessment Components (Fiscal Year Due Date)
Assessment of Global Change Effects on Tropospheric Ozone	
How will global climate change affect local and regional weather patterns which influence air quality? (1)	1. Develop set of meteorological variables needed for air quality simulations. (2002) • Obtain source code for the Regional Climate Model/Mesoscale Model5 (RCM/MM5) • Obtain General Circulation Model (GCM) output data for use as input data to RCM/MM5 • Implement RCM/MM5 on EPA National Environmental Supercomputing Center Cray T3E and UC Davis Beowulf computer • Run baseline and future climate scenarios based on GCM output data • Review scenarios
What is the quantitative effect of global change on tropospheric concentrations of ozone? (2,4) Which geographic areas will experience the largest changes (positive and negative) due to global change? (2,4) How many areas will fail to attain the ozone levels required by NAAQS due to global change? (2,4)	2. Statistically analyze the relationship between tropospheric ozone and weather. (2001)
What is the effect of global change on emissions of ozone precursors? (3)	3. Develop baseline and future emissions scenarios. (2003) • Driver scenarios based on existing scenarios of economic growth, energy demand, population growth, and vehicle miles traveled • Policy scenarios • Future anthropogenic emissions scenarios • Future biogenic emissions scenarios
	4. Develop basecase ozone simulations and simulate future ozone scenarios (2004)
How would societal changes and technology advancements adopted either to respond to climate change or to reduce harmful ambient levels of tropospheric ozone influence emissions of tropospheric ozone precursors? What combinations of human adaptive responses would provide the greatest reduction in ozone precursors at the lowest cost? (5) What should be communicated to stakeholders about the effects of global change on tropospheric ozone and potential adaptation options? (5)	5. Develop a peer-reviewed assessment report on global change effects on tropospheric ozone (2004)
Assessment of Global Change Effects on Particulate Matter	
What will be the effect on fine particulate concentrations of elevated temperatures and other meteorological changes that may occur with global change? (1, 2, 4)	1. Conduct workshop for setting research agenda re: the global change effects on particulate matter. (2001)
What is the quantitative effect of global change on atmospheric concentrations of particulates? (2,4) Which geographic areas will experience the largest changes (positive and negative) due to global change? (2,4) How many areas will exceed the NAAQS for particulates due to global change? (2,4)	2. Statistically analyze the relationship between particulate matter and weather. (2003)
What is the effect of global change on particulate emissions? (3)	3. Develop baseline (2005) and future emissions scenarios. (2006)

How would societal changes and technology advancements adopted either to respond to climate change or to reduce harmful ambient levels of particulate matter influence particulate emissions? What combinations of human adaptive responses would provide the greatest reduction in particulate matter at the lowest cost? (5) What should be communicated to stakeholders about the effects of global change on particulate matter and potential adaptation options? (5)	• Driver scenarios based on existing scenarios of economic growth, energy demand, population growth, and vehicle miles traveled • Policy scenarios • Future anthropogenic emissions scenarios • Future biogenic emissions scenarios 4. Develop base case particulate matter simulations. (2007) and simulate future particulate matter scenarios. (2007) 5. Develop a peer-reviewed assessment report on global change effects on particulate matter. (2008)

FOCUS AREA IV: WATER QUALITY

Assessing the effects of global change on water quality

The objective of the Clean Water Act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." To achieve this objective, watersheds and their aquatic ecosystems are being restored and protected to improve human health, enhance water quality, reduce flooding, and provide habitat for wildlife. The Global Change Program will assess the effects of global change on the provision of clean and safe drinking water, the protection of surface waters, and the treatment of waste water.

Water quality is currently threatened by pollutants and pathogens (*e.g.*, nutrients, sediments, microbial pathogens, pesticides, and other toxic pollutants) and alterations in freshwater habitats, streamflow, and water temperatures. These threats to water quality could be exacerbated or ameliorated by climate change, climate variability or land-use change. Changes in climate and climate variability may affect water quality, primarily through changes in runoff. Runoff is water that does not evaporate or seep into the soil, but flows into streams, rivers, or lakes, and may carry pollutants [IPCC 1998, p. 502]. Climate models predict increases in both precipitation and evapotranspiration globally, with regional variations. Runoff will increase in areas where increases in precipitation exceed increases in evapotranspiration. Depending on land-use choices, the increased runoff may increase the runoff of pollutants as well. Paving or grading surfaces increases the amount, speed, and temperature of runoff, thus increasing stream temperatures and disrupting natural streamflows. Increases in storm intensity can have the same effect. High runoff speeds generally move more pollutants. Conversely, wetlands and riparian buffer zones can slow runoff, filter out pollutants, and moderate alterations of temperature and streamflow. Increases in pollutant runoff may increase concentrations of pollutants in a water body, depending on the diluting effects of the increased runoff. If evapotranspiration rates exceed precipitation, runoff will drop, and pollutant runoff will drop as well. However, this can have the effect of concentrating pollutants in the water body as water levels drop. Changes in climate that produce higher water temperatures, lower flows, and lower water levels will increase the negative effects of wastewater on freshwater ecosystems (IPCC 1998).

The Global Change Program will assess the effects of global change — changes in climate, climate variability, and land-use — on water quality, thus helping the Agency to fulfill its commitment to safeguard the Nation's waters. Specifically, the Program plans to assess the consequences of global change for:

- water quality related to pollutants and microbial pathogens (2005), and
- water quality related to biocriteria (2008).

Pollutants and microbial pathogens

Global change could alter the concentrations of pollutants and pathogens in surface and ground waters. These changes could have ramifications for aquatic ecosystems, human recreational uses, and drinking water. The Global Change Program will examine the ability of public water systems to respond to altered drinking water and waste water treatment needs due to global change. In addition, the availability of adaptation options to protect surface waters for aquatic ecosystems and for recreational uses will be explored.

Nutrients, microbial pathogens, pesticides and other toxics pose a variety of risks to humans and aquatic life. In addition, saltwater intrusion poses a risk to aquatic life and coastal drinking supplies. In 1999, about 10% of public water failed to meet health-based drinking water standards. Many of these violations were related to microbial pathogens. EPA's Science Advisory Board concluded in 1990 that exposure to microbial contaminants such as bacteria, viruses, and protozoa (e.g., *Giardia lamblia* or *Cryptosporidium*) was likely the greatest remaining health risk management challenge for drinking water suppliers (www.epa.gov/OGWDW/mdbp/mdbp.html). In 2000, the EPA reported that over 20,000 water bodies have been identified as polluted.

(www.epa.gov/owow/tmdl/finalrule/factsheet1.html). Nutrient pollution is a particularly serious problem. According to EPA's *National Water Quality Inventory: 1994 Report to Congress*, excessive nutrient enrichment impairs 23% of the nation's surveyed rivers, 43% of its surveyed lakes, and 47% of its surveyed estuaries (EPA 1998a).

Making the Connection — from Water Quality Research to Assessment

ORD's expertise in developing and testing water treatment technologies and in modeling and analyzing surface water systems will be applied to assess adaptation needs and options for water system managers. ORD researchers are modeling the effects of a range of climate change scenarios on runoff in the Ohio River basin and examining the impacts of these changes on surface water quality. Changes in pollutant concentrations in surface waters may affect the ability of drinking water and waste water treatment systems to meet water quality standards.

The Global Change Program's assessment of pollutants and pathogens will focus on three aspects of water quality: drinking water infrastructure, wastewater treatment, and surface water quality. Municipal and industrial waste waters must be treated in order to protect downstream water quality. The quality of surface waters affects the ability of municipalities to use the surface water as a drinking water source and the ability of the aquatic ecosystems to support aquatic life and recreation. The Global Change Program's assessment will assess the consequences of global change for these three aspects, and will examine the potential for adaptive responses to protect drinking and surface waters for human and ecosystem uses. The interconnectedness of the three aspects may provide opportunities to look at multiple benefits associated with watershed protection strategies. Table 7 outlines the research questions that will guide the assessment and the components necessary to complete the assessment. These components map directly into capabilities at the labs and centers and those of the extramural grants program (see Program Capabilities, p. 10-11).

Biocriteria

To comply with the Clean Water Act's requirement that state water quality standards shall consist of designated uses and the criteria for protecting such uses (Section 303(c)(2)(A)), and with the objective of restoring the biological integrity of the nation's waters, EPA is working with states to develop biocriteria (Section 101(a)). The Water Quality Criteria and Standards Program is pursuing the development of biocriteria as an improved basis for aquatic life protection because "biocriteria and bioassessments will help to identify ... the cumulative impacts of all stressors within a water body" (EPA 1998a). Biological indicators are used to measure the ability of a water body to support aquatic life; biocriteria are those attributes that a water body should possess to support aquatic life (Gibson 1996). The EPA has developed technical guidance documents to assist states and tribal nations in developing biological assessment methods and criteria for streams and wadeable rivers and for lakes and reservoirs. The states are in the process of implementing these methods, and three states (Ohio, Maine and Florida) have developed numerical biocriteria for streams and wadeable rivers.

The ability of states to attain biocriteria will be influenced by changes in climate, climate variability, land-use and UV radiation. These global changes could alter water temperatures, stream morphology, stream flow and lake levels, UV effects on aquatic life, pollutant concentrations in water bodies, and sedimentation. These changes will in turn affect aquatic life and be reflected by changes in biological indicators that are used for biocriteria. (See also the assessment of Aquatic Ecosystems in the Ecosystems Focus Area and the assessment of Pollutants and Pathogens in the Water Quality Focus Area. These assessments will contribute to the Biocriteria assessment.)

The Global Change Program will develop a framework that states can use to assess the effects of global change on their ability to meet biocriteria and to identify adaptation strategies to cope with global change. Detailed studies will be conducted in two to four states that have established biocriteria for streams and wadeable rivers. Later detailed studies will expand the

framework to biocriteria for lakes and reservoirs. The final step of the analysis will evaluate the applicability of the framework to states that were not included in the detailed studies. Table 7 outlines the research questions that will guide the assessment and the components necessary to complete the assessment.

Table 7. Focus Area IV: Water Quality

Research Questions (see related Assessment Component in next column)	Assessment Components (Fiscal Year Due Date)
Assessment of Impact of Global Change on Water Quality: Pollutants and Microbial Pathogens	
Which pollutants do public water systems currently have difficulty treating? (1) How may global change affect the loads of those pollutants? What new challenges may arise due to global change? (1) Will public water systems be able to treat changing loads of pollutants or handle new challenges? (1) How much will treatment to meet current standards under future conditions cost? (1) Are there alternatives to traditional treatment methods, what do they cost, and what other benefits or costs do they incur? (1)	1. Assessment of Drinking Water Infrastructure (2001) • Draw from current reports to identify current challenges involved in meeting Safe Drinking Water Act and Amendments (SDWAA) standards • Estimate effects of global change on those challenges. Identify possible new challenges. • Determine if current treatment methods are adequate for future treatment needs based on future global change impacts (to meet SDWAA standards) • Identify costs of any additional treatment needs • Identify alternative approaches to treatment, their costs, and multiple benefits.
Do communities rely on coastal aquifers and rivers for their public water supplies? How many people are served? (2) Are rising seas, storm surges, and changes in river flows likely to lead to saltwater intrusion in public water systems? (2) What can be done to protect water supplies? (2)	2. Assessment of Sea Level Rise on Coastal Aquifers and Rivers (2001) • Identify public water systems that rely on coastal rivers and aquifers for their water supply. Identify numbers of people served by those systems • Utilize existing projections of sea-level rise and changes in river flow to determine vulnerability of public water systems • Develop options for adaptation and their costs
Which pollutants currently inhibit attainment of water quality criteria, and what are their sources? (3) If those pollutants are susceptible to changes in runoff and land-use, how may future changes in climate and land-use affect water quality? (3) What adaptation strategies might water resource managers and other stakeholders use to achieve water quality criteria for surface waters under conditions of global change? (3)	3. Assessment of Pollutants and Pathogens in Surface Waters (2003) • Determine from available sources which pollutants and pathogens currently pose problems for lakes, rivers, and streams, and identify the sources of those pollutants and pathogens. • Use existing land-use, regional climate, and hydrology models to estimate how climate and land-use change may alter the concentrations of pollutants and pathogens in surface waters. • Identify approaches for adapting to global change.

What challenges do industrial and municipal waste water treatment systems face currently? (4) How may climate and land-use change exacerbate or ameliorate those challenges? (4) What changes in treatment methods may be needed to respond to current and future challenges and meet water quality standards? (4) How much will it cost to respond to current or future challenges? (4) What range of approaches is available to protect water resources? (4)	4. Assessment of Waste Water Treatment (2003) • Determine from available sources current challenges for wastewater treatment facilities. • Utilize federal and private research to obtain regionally specific climate change, land-use, and hydrology scenarios. • Determine changes needed in treatment in order to meet receiving water standards under conditions of global change • Determine costs associated with changing treatment requirements • Identify alternative approaches to treatment, their costs, and multiple benefits.
How can we effectively summarize what we have learned about global change impacts on pollutants and microbial pathogens for stakeholders? (5)	5. Develop a peer-reviewed assessment report summarizing findings on global change impacts on pollutants and microbial pathogens. (2005) • Summarize the findings of the drinking water, wastewater, and pollutant and pathogen studies, including the options for adaptation and consideration of multiple benefits approaches.
Assessment of Impact of Global Change on Water Quality: Biocriteria	
Which biological indicators may be used, or are being used, by the states to develop biocriteria for streams and wadeable rivers? (1) Which of these biological indicators might be sensitive to climate variability and change? to land-use change? to UV radiation? (1) How could changes in climate, climate variability, land-use and UV radiation affect states' abilities to attain biocriteria in their streams and wadeable rivers? (1)	1. Develop a paper describing the potential sensitivity of biocriteria for lakes, rivers and streams to climate change and variability, changes in land-use and UV radiation. Convene an expert workshop to review the paper and establish consensus on its conclusions. (FY2004) • Identify biological indicators that can be used by states to develop biocriteria. • Adapt the conceptual model developed for the Aquatic Ecosystems assessment to include these indicators. Include relevant information from the Pollutants and Pathogens assessment.
How can states identify adaptation strategies that could help them attain biocriteria in the face of global change? (2)	2. Develop a paper that outlines a framework that states could use to identify adaptation strategies that could help them meet biocriteria, given potential changes in land-use, climate, climate variability, and UV radiation. Convene an expert panel to review the adaptation paper and establish consensus on the its conclusions. (FY2005) • Use the first paper to identify challenges that states might face in meeting biocriteria under conditions of global change. • Draw on expert opinion, literature review, and the previous assessments of Aquatic Ecosystems and Pollutants and Pathogens for information about adaptation options.
How can state-specific analyses improve our understanding of the vulnerability of streams and wadeable rivers (as measured by states' ability to attain biocriteria) to global change? (3) Are the biological indicators sensitive to global change as forecasted by scenarios? Could global change affect the ability of these states to meet biocriteria? (3) What adaptation options are available to states? How do adaptation options link to other environmental programs (e.g., NPDES, TMDL, watershed protection, ecological restoration)? (3)	3. Conduct detailed studies in 2-4 states (e.g., Ohio, Maine and Florida) that have established biocriteria for streams and wadeable rivers. Work with the states and EPA's Office of Water to test the framework for assessing potential effects of global change on the ability of states to meet biocriteria for streams and wadeable rivers and assess adaptation options to cope with global change. (FY2006) • Use or adapt existing climate, land-use, and UV scenarios for the identified states. • Identify which biocriteria for streams and wadeable rivers for these states are potentially sensitive to global change. • Evaluate the direction, approximate magnitude, and level of

	uncertainty for the effects of global change on biological indicators used as biocriteria by states. • Identify adaptation options that could help these states meet their biocriteria.
How does the framework need to be modified to apply to lakes? (4) What is the vulnerability of lakes (as measured by states' ability to attain biocriteria) to global change? (4) What adaptation options are available to states? (4)	4. Expand the framework so that it can address biocriteria for lakes. (FY2007) • Develop a paper, adapting the approach used in the first two papers (about the sensitivity of biocriteria for streams and wadeable rivers and adaptation options for these systems) and apply it to lakes. • Conduct detailed studies in previously studied states (e.g., Ohio, Maine and Florida) and/or in new ones to assess potential effects of global change on their ability to meet biocriteria for lakes. Assess adaptation options to cope with global change.
What biological indicators are used by other states to develop biocriteria? (5) Are the results developed for specific states for streams, wadeable rivers and lakes applicable to biological indicators used by other states and global change scenarios for other states? (5)	5. Evaluate the applicability of the framework for states that were not included in the detailed studies of specific states. (FY2007) • Identify which biological indicators are used by other states that have developed biocriteria. • Using conceptual models, evaluate whether the framework, developed by specific states for specific biological indicators, global change scenarios, and adaptation options, is applicable to other states.
What should we communicate to states, the EPA Office of Water, and other stakeholders to facilitate their understanding of the vulnerability of aquatic ecosystems - as measured by their attainment of biocriteria - to global change, and to aid their evaluation of adaptation options? (6)	6. Prepare a final report that describes a framework that states can use to assess their vulnerability, with respect to biocriteria, to global change and what adaptation options are available to them to help them meet biocriteria in the face of global change. The report will include results for particular states that were developed in the case studies and extrapolate those results, as appropriate, to other situations. (FY2008)

EPILOGUE

This *Research Strategy* outlines an ambitious ten-year plan for the Global Change Research Program. The assessment orientation is a significant departure from global change research conducted by ORD in the past. A redirection of such proportions has not been easy, and without the cooperation and collaboration of individuals and institutions across ORD it would not have been possible.

The redirection is necessary, however, if we are to satisfy the needs of our stakeholders. The aim of the assessments described in this *Strategy* is to provide scientifically sound support to stakeholders as they try to make policy and resource management decisions under conditions of uncertainty. By providing a better understanding of the consequences of a range of actions, including inaction, the Global Change Program will be poised to inform the difficult choices expected of decision makers.

The redirection is also necessary to make the most of limited research budgets, and to ensure that the various Federal Agencies coordinate their efforts to exploit relative strengths. EPA's strength lies in assessments of the possible impacts of global change. ORD will not be able to fulfill the expectations outlined in this *Strategy* without the contributions of all of the constituent labs and centers, our academic partners, and the general stakeholder community.

GLOSSARY and IMPORTANT CONCEPTS

adaptability (or adaptation)

Adaptation refers to human interventions that can be carried out in response to, or in anticipation of, changes in condition due to projected or actual changes in climate and other environmental stresses.

assessment

An iterative analytic process that engages both analysts and end-users to evaluate and interpret the interactions of dynamic physical, biological, and social systems and communicate useful insights about the significant causes and likely consequences of global change (NAWG 1999).

biocriteria

Biocriteria are the specific attributes that a water body should possess, and thus can be used in biological assessment to determine how well a water body supports aquatic life (Gibson 1996). Biological assessments of aquatic ecosystems examine the density and relative abundance of resident organisms, the condition of their immediate habitat, and the condition of their watershed. Sites that are being evaluated are compared against a specified reference condition to determine the level and nature of impairment (Larsen 1997).

biodiversity

"The variability among living organisms from all sources, including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems" (UNEP 1995, p.8, adopted from Article 2, "Use of Terms", in the Convention on Biological Diversity).

climate

The average course or condition of the weather at a place, usually over a period of 30 years or more.

climate change

"Any change in climate over time whether due to natural variability or as a result of human activity" (IPCC 1996c, p.3).

climate variability

Fluctuations in climate at different time scales, e.g., seasonal, annual, inter-annual, decadal, and beyond, usually expressed on a regional basis.

conceptual model

A written description and visual representation of predicted relationships between ecological entities and the stressors to which they may be exposed. Conceptual models are developed from information about stressors, potential exposure, and predicted effects on an ecological entity. Conceptual models consist of two principal components: 1) a set of risk hypotheses that describe predicted relationships among stressor, exposure, and assessment endpoint response, along with the rationale for their selection, and 2) a diagram that illustrates the relationships presented in the risk hypotheses. (U.S. EPA 1998c)

ecosystem

"All individuals, species, and populations in a spatially defined area, the interactions among them, and those between the organisms and the abiotic environment" (UNEP 1995, p. 281).

ecosystem functioning

"The sum total of processes operating at the ecosystem level, such as the cycling of matter, energy, and nutrients, as well as those processes operating at lower ecological levels which impact on patterns or processes at the ecosystem level" (UNEP 1995, p.281).

ecosystem services

"The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life" (Daily 1997, p.3).

extreme event

A climatic event that is a deviation from normal climate, and that has a finite but usually low probability of occurring in a particular place. Examples include extreme precipitation events (floods, droughts), extreme temperature events,

extreme wind events (tornados, hurricanes, etc.).

global change

Changes in the global environment (including alterations in climate, land use and productivity, oceans and other water resources, atmospheric chemistry, and ecological systems) that occur at rates that may alter the capacity of the Earth to sustain life.

human dimensions of global change

"Encompasses analysis of the human causes of global environmental transformations, the consequences of such changes for societies and economies, and the ways in which people and institutions respond to the changes. It also involves the broader social, political, and economic processes and institutions that frame human interactions with the environment and influence human behavior and decisions" (NRC 1999, p.295).

land cover

"The pattern of ecological resources and human activities dominating different areas of the earth's surface" (EPA 1997). A land cover category is "that which overlays or currently covers the ground, especially vegetation, permanent snow and ice fields, water bodies, or structures. Barren land is also considered a "land cover" although technically it is lack of cover. Land cover can be thought of as applying to the setting in which action (one or more different land-uses) takes place" (USDA 1989).

land-use

Refers to the purpose to which land is put (e.g., protected areas, forestry for timber products, plantations, row-crop agriculture, pastures, or human settlements). Land cover, which is the ecological state and physical appearance of the land, is often used as a proxy for land-use (Daly *et al.* 1999).

potential multiple benefits or co-benefits

Secondary benefits associated with strategies to address the risks and opportunities created by global change.

resilience

The ability of an ecosystem (or other system) to maintain its valuable attributes despite pressures upon the system exerted by stressors.

sensitivity

In the context of climate change, sensitivity is defined as "the degree to which a system will respond to a change in climatic conditions (e.g., the extent of change in ecosystem composition, structure, and functioning, including primary productivity, resulting from a given change in temperature or precipitation)" (IPCC WGII 1996).

stakeholder

"Any organization, governmental entity, or individual that has a stake in or may be impacted by a given approach to environmental regulation, pollution prevention, energy conservation, etc." (EPA 1999).

stressor

"Any physical, chemical, or biological entity that can induce an adverse response" (EPA 1998c).

vulnerability

In the context of climate change, vulnerability is defined as "the extent to which climate change may damage or harm a system. It depends not only on a system's sensitivity but also on its ability to adapt to new climatic conditions" (IPCC WGII 1996).

APPENDIX A: HISTORICAL OVERVIEW

Prior to the significant redirection described in this document, the Global Change Program traditionally responded to USGCRP goals of data collection (*e.g.*, carbon flux tracking), process-oriented research (*e.g.*, carbon cycle analysis and development of carbon sequestration options). Another focus of the program was on the development of technologies to mitigate greenhouse gas emissions. The shift towards an assessment-oriented program entails significant disinvestments in specific activities and redirections of resources. Today, the Global Change Program no longer addresses mitigation policies, technology development, carbon cycle analysis, and carbon sequestration issues.

While the redirection of the Global Change Program was based in large part on a fundamental shift in priorities and on the focusing of the USGCRP mandate to member agencies, the budgetary figures for the 1990s (Figure 4) reflect an additional impetus for change — the need for program restructuring given the significant added constraints of a nearly 50% reduction in budgetary resources from 1994 to 1997.

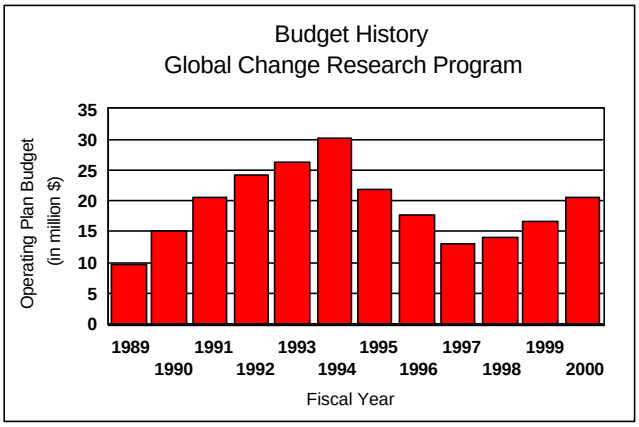

Figure 4. Budgetary History of ORD's Global Change Program

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APPENDIX B: GLOBAL CHANGE RESEARCH ACT of 1990

U.S. Global Change Research Program Act of 1990
Public Law 101-606(11/16/90) 104 Stat. 3096-3104

An Act to require the establishment of a United States Global Change Research Program aimed at understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment, to promote discussions toward international protocols in global change research, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Global Change Research Act of 1990".

TITLE I--UNITED STATES GLOBAL CHANGE RESEARCH PROGRAM

SEC. 101. Findings And Purpose.

(a) FINDINGS — The Congress makes the following findings:
1. Industrial, agricultural, and other human activities, coupled with an expanding world population, are contributing to processes of Global change that may significantly alter the Earth habitat within a few human generations.
2. Such human-induced changes, in conjunction with natural fluctuations, may lead to significant global warming and thus alter world climate patterns and increase Global sea levels. Over the next century, these consequences could adversely affect world agricultural and marine production, coastal habitability, biological diversity, human health, and Global economic and social well-being.
3. The release of chlorofluorocarbons and other stratospheric ozone-depleting substances is rapidly reducing the ability of the atmosphere to screen out harmful ultraviolet radiation, which could adversely affect human health and ecological systems.
4. Development of effective policies to abate, mitigate, and cope with Global change will rely on greatly improved scientific understanding of Global environmental processes and on our ability to distinguish human-induced from natural Global change.
5. New developments in interdisciplinary Earth sciences, Global observing systems, and computing technology make possible significant advances in the scientific understanding and prediction of these Global changes and their effects.
6. Although significant Federal Global change research efforts are underway, an effective Federal research program will require efficient interagency coordination, and coordination with the research activities of State, private, and international entities.

(b) PURPOSE — The purpose of this title is to provide for development and coordination of a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change.

SEC. 106. SCIENTIFIC ASSESSMENT.

On a periodic basis (not less frequently than every 4 years), the Council, through the Committee, shall prepare and submit to the President and the Congress an assessment which —

- integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings;
- analyzes the effects of Global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and
- analyzes current trends in Global change, both human- induced and natural, and projects major trends for the subsequent 25 to 100 years.

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