Complex Environmental Systems

Synthesis for Earth, Life, and Society in the 21st Century

A 10-Year Outlook for the National Science Foundation

NSF Advisory Committee for Environmental Research and Education

About the Advisory Committee for Environmental Research and Education

In 2000, the National Science Foundation (NSF) established the Advisory Committee for Environmental Research and Education (AC-ERE) under the Federal Advisory Committee Act (FACA) to:

- Provide advice, recommendations, and oversight concerning support for NSF's environmental research and education portfolio.
- Be a base of contact with the scientific community to inform NSF of the impact of its research support and NSF-wide policies on the scientific community.
- Serve as a forum for consideration of interdisciplinary environmental topics as well as environmental activities in a wide range of disciplines.
- Provide broad input into long-range plans and partnership opportunities.
- Perform oversight of program management, overall program balance, and other aspects of program performance for environmental research and education activities.

The AC-ERE includes scientists, engineers, and educators from many disciplines, including a member from each of the other NSF advisory committees. The AC-ERE focuses on issues related to the coordination, integration, and management of environmental programs across the Foundation, but is particularly concerned with those aspects that affect multiple disciplines, such as cyberinfrastructure, digital libraries, and interdisciplinary programs, centers, and major instrumentation.

In preparing this Outlook for the first decade of the 21st century, the AC-ERE focused on environmental activities that cross disciplinary boundaries or support NSF's environmental portfolio. The AC-ERE considered numerous reports on environmental science and engineering and received considerable public comment on early drafts. As a result, this Outlook provides broad-based guidance to NSF about environmental research and education that is aligned with its mission.

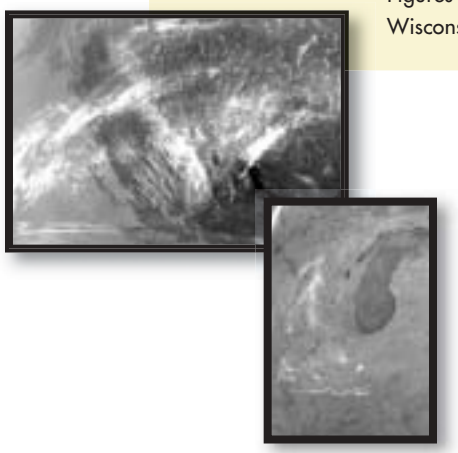
Environmental Synthesis

As the global footprint of human activity continues to expand, environmental science and engineering problems will provide great challenges and opportunities in the next decade. Because of the complex relationships among people, ecosystems, and the biosphere, human health and well-being are closely linked to the integrity of local, regional, and global ecosystems. Therefore, environmental research and education are central elements of local, national, and global security, health, and prosperity.

New instrumentation, data-handling, and methodological capabilities have expanded the horizons of what we can study and understand about the environment. These advances create the demand for collaborative teams of engineers and natural and social scientists that go beyond current disciplinary research and educational frameworks. Imagination, diversity, and the capacity to adapt quickly have become essential qualities for both institutions and individuals, not only to facilitate research, but to ensure the immediate and broad-based application of research results related to the environment.

For anyone who doubts that humans are affecting Earth's environment, the grounding of all commercial aircraft for three days after the September 11, 2001 terrorist attacks provided a striking example. Atmospheric scientists measured the effects of jet condensation trails (contrails)—miles above our view and usually well beyond our thoughts—on the surface temperature of our planet. Scientists compared average daytime temperature ranges during the three-day time period with those of the last 30 years. The bottom line? Passage of jets through our atmosphere is changing Earth's temperature. Even in the skies above us, humans are interacting with their environment in ways that many of us seldom consider.

Figures courtesy of David J. Travis, University of Wisconsin-Whitewater. NSF grant BCS-0099011.



To meet these complex challenges as well as urgent human needs, we need to develop environmental synthesis to:

- frame questions or problems for investigation,
- integrate research activity,
- conduct meta-analyses (the synthesis of existing data sets from diverse fields and sources) to define the state of knowledge, and
- make the resulting scientific data, models, and conclusions publicly accessible.

Research must integrate spatial, temporal, and organizational scales, draw from many disciplines, and facilitate the synergy that results from partnerships among governmental, academic, and private organizations. This research must use diverse datasets and approaches and be effectively communicated among researchers, educators, students, resource and industrial managers, policy makers and the public.

Research Frontiers

To advance the fundamental knowledge necessary to address critical environmental challenges, the Advisory Committee for Environmental Research and Education recommends increased focus on three interrelated areas:

- coupled human and natural systems,
- coupled biological and physical systems,
- people and technology.

Research in these critical areas is important, timely, feasible, and likely to lead to significant scientific and technological outcomes in the next decade.

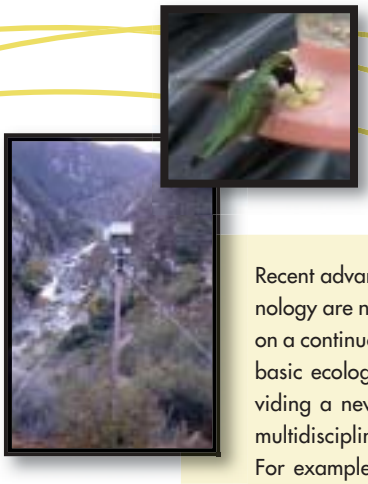
Many environmental systems are a nexus for human needs, ecosystem functioning, and engineering creativity. An example of synthesis research centers around the installation and operation of large dams. Dams can cause radical changes in river landscapes and aquatic habitats for miles downstream. In some places, fish habitats have abruptly declined after dam installation, whereas bird habitats have expanded as riparian forests have filled in drier bottomlands where river waters once flowed. The effects reach far beyond what we currently can observe and measure, to cascading alterations in landscapes and ecosystems the longer dams are left in place. Photos courtesy of William L. Graf, University of South Carolina. NSF grant BCS-0099011.

Coupled human and natural systems research explores the complex web of environmental relationships and feedbacks at diverse temporal and spatial scales. It integrates population, ecosystem, and socioeconomic models to understand and enable response to issues such as landscape fragmentation, spread of pathogens, and water resources. Research challenges include: (1) land, resources, and the built environment, (2) human health and the environment, (3) freshwater resources, estuaries, and coastal environments, and (4) environmental services and valuation.

Coupled biological and physical systems research focuses on understanding the systems, processes, and dynamics that shape the physical, chemical, and biological environment at all scales. It seeks to improve observing systems for exploring the effects of humans on environmental cycles and biodiversity. Research areas include: (1) biogeochemical cycles, (2) climate variability and change, and (3) biodiversity and ecosystem dynamics.

People and technology research seeks to understand how individuals and institutions interact with the environment, how they use resources and respond to change, and how they create and implement new technologies. Among its goals are creating new technologies that protect and improve the environment and identifying best practices for communicating risk and organizing responses to natural hazards. Research challenges include: (1) materials and process development, (2) decision making and uncertainty, and (3) institutions and environmental systems.

Building Capacity



Recent advances in wireless networking and sensor technology are now permitting us to monitor our environment on a continuous basis, giving us more data to understand basic ecological and earth science processes, and providing a new "cyberinfrastructure" in which to conduct multidisciplinary research and make policy decisions. For example, the High Performance Wireless Research and Education Network (HPWREN) permits ecologists to stream sensor data directly from the Santa Margarita Ecological Reserve in California to their campus laboratories for analysis, hydrologists to measure parameters such as water acidity and pressure, and biologists to track animal calls and other wildlife activity—without even being in the field. Meanwhile, cameras linked to HPWREN allow researchers to catch a glimpse of a biologically diverse area where mountain lions roam, golden eagles nest, and hummingbirds sip nectar. Photos courtesy HPWREN. NSF grant ANI-0087344.

To fulfill this research Outlook and to support a new generation of environmental professionals, the Advisory Committee recommends major investments in environmental education, training, infrastructure, and technical capacity. Scientists, engineers, technicians, resource managers, and educators must be prepared to cross disciplines, integrate diverse information, and collaborate to solve environmental problems. Long-term, dynamic partnerships that cross national and regional jurisdictions and international boundaries are needed to address multi-scale challenges. Developing the requisite cyberinfrastructure—advanced data assimilation and curation, networking, modeling, and simulation tools for large-scale, systems level, integrated applications—is key to making progress in the decade ahead.

Environmental education should be used as an integrating concept in pre-school, elementary, and secondary education. At two- and four-year colleges and research institutions, academic institutional structures and incentives should facilitate interdisciplinary environmental research, increased diversity in the environmental workforce, and productive interactions with policy makers and the community. Informal education about the environment is also a critical component of enhancing public understanding of complex environmental information and decisions. Increased participation by under-represented groups is imperative to achieving and shaping the environmental research and education agenda.

Infrastructure and technical capacity must also be expanded and strengthened to address the environmental challenges of the coming decade. As sensors, instruments, and observing systems continue to improve, and the quantity and quality of environmental data grow rapidly, cyberinfrastructure must evolve quickly to archive, integrate, interpret, and communicate environmental information. Environmental cyberinfrastructure and observing systems are long-term and expensive endeavors requiring the efforts of multiple agencies. Interdisciplinary research also necessarily relies on experiments, models, and their integration to understand environmental systems at multiple scales and to develop scenarios and projections that are relevant to policy.

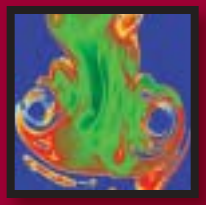
Future Directions

This Outlook recommends major directions in interdisciplinary environmental research and education that NSF should follow over the next decade (2003-2012). If these research directions are adequately funded and supported, and productive research is carried out, we will be able to significantly expand our base of knowledge and synthesis of environmental systems and technologies. These investments in people, ideas, and tools, when combined with the efforts of NSF's many partners, can provide solutions to some of today's environmental problems and enable continued growth in our capability to respond to new challenges. There will always be a new scientific and engineering frontier, but this Outlook will move us toward the goal of achieving long-term environmental robustness, health, and well-being.

To move ahead in this decade, environmental researchers need clearly articulated programs with sufficient long-term funding horizons so they can incorporate interdisciplinary approaches and address complex environmental questions and problems. Programs must respond to the needs of individuals, small groups, and large groups, as well as collaborations within and among institutions. It often takes several years for interdisciplinary teams to learn how to work together, make progress in innovative directions, and synthesize the results. The need for long-term funding is therefore particularly acute for environmental research and education.

The first years of the 21st century are already presenting serious environmental challenges, including climate change and an array of biological threats. As our technological and research capacity increases, along with the footprint of human activity, we are faced with both the promise of understanding the environment and our relationship to it, and the responsibility of making wise decisions about the design and use of technology and about managing the complex relationships among people, ecosystems, and planetary processes. In this exciting and productive next decade, environmental research and education will be critical for local, national, and global security, health, and prosperity.

The Garden Mosaics program promotes science learning, as well as intergenerational and multicultural understanding, through youth-conducted research in urban community gardens. Youth engaged in Garden Mosaics collect data for a national database, focused on answering three questions: What horticultural, social, environmental, and educational amenities do community gardens provide for their neighborhoods? Are there any other sites in these urban communities where residents can access these amenities? What horticultural practices are implemented by community gardeners, many of whom are recent immigrants from developing countries and African-Americans with roots in the rural South? Youth use a number of methods to answer these questions, including interviews with gardeners and air photo and map interpretation. The results of the youths' research are posted to gardenmosaics@cornell.edu, and are available to greening organizations, agricultural and social scientists, gardeners, and others interested in community gardens and ethnic horticultural practices. Photos courtesy of Marianne Krasny, Cornell University. NSF grant ESI-0125582.


The National Science Foundation is a federal agency, established by Congress in 1950. NSF is authorized to support basic scientific research, to support research fundamental to engineering processes, and to strengthen science and engineering education at all levels. NSF is the largest federal supporter of environmental research and education in academe and one of the major federal supporters of all such research. NSF promotes research necessary for improved understanding of complex environmental processes at multiple scales. NSF's programs in disciplinary research, focused interdisciplinary research, and a broad range of educational, international, and outreach functions lead to knowledge, methods, and new technologies that can enable solutions to critical environmental problems. Certain environmental research activities are managed as partnerships with other agencies, such as the Environmental Protection Agency, the Department of Energy, and the U.S. Geological Survey. More information on NSF's environmental programs is available at www.nsf.gov/ere.

Copies of the full (68-page) Outlook report are available upon request. An email request form is available at www.nsf.gov/ere.

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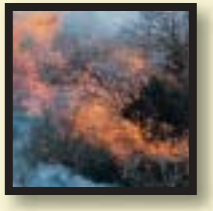
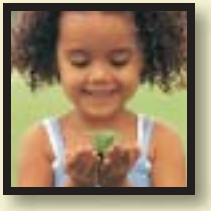
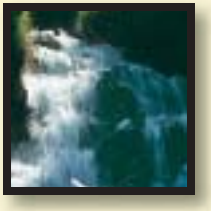

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