EARTH SURFACE DYNAMICS PROGRAM

Program Plan 2005-2010

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U.S. Department of the Interior
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EXECUTIVE SUMMARY

Many observations of natural phenomena suggest that we are living in a time of rapidly changing climates. These changes need to be set against the long-term pattern of climate change and variability, which is provided by studying the geologic record of climate change. A large number of scientific organizations have come to the conclusion that human activities are increasingly altering the Earth's climate (mainly though increasing concentrations of greenhouse gasses) and add to the effects of natural climate change and variability. Understanding the nature and magnitude of past climate and environmental changes is necessary to provide a baseline against which to identify the effects of humans as agents of environmental change and to provide a long-term perspective on climate variability

The Earth Surface Dynamics Program (ESDP) supports multidisciplinary studies of past environmental and climatic changes (climate history); process studies that explore the sensitivity of the Earth-surface and associated ecosystems to climate variability; and forecasting of potential future changes and their effects on landscapes, land use, and ecosystems (particularly on public lands). The combination of these studies provides integrated long-term perspectives on the effects of climatic changes and variability and on the interactions through time among climatic, geologic, biologic, and human systems on regional and landscape scales. These studies provide information to allow policymakers and land and resource managers to gauge the relative sensitivity of particular ecosystems, resources, and regions to climatic change and variability.

The Earth Surface Dynamics Program (ESDP) aims to be the primary provider of scientific information on past, present, and future climates and their effects on earth and human systems to fulfill the mission of the US Geological Survey. Program activities also support the strategic goals of the US Climate Change Science Program (CCSP).

The program has identified four major goals to achieve this vision:

1. Understand climatic and environmental change and variability on different time scales

2. Determine the effects of climate change and variability on terrestrial and marine systems on different time scales

3. Develop a fundamental understanding of processes that govern interactions among climate, earth surface processes, and marine and terrestrial ecosystems

4. Anticipate the effects of climate change and variability on natural and human systems under a range of plausible future climate scenarios.

For each goal, the program has identified a series of objectives and strategies that will guide execution of program goals through research projects funded by the program. For each program goal, end outcome measures and performance metrics have been identified.

1. INTRODUCTION

1.1 Overview – the importance of climate change research

Many observations of natural phenomena suggest that we are living in a time of rapidly changing climates. Instrumental records indicate a sharp rise in northern hemisphere temperatures since the early 1900's and this appears to be manifested today in a shrinking Arctic sea cover, melting of permafrost in Alaska and elsewhere, earlier blooming of plants, changes to the timing of spring melting of snow and ice, and many other changes in the Earth system. Climate change and variability have been identified by many scientific organizations and policy makers as one of the major challenges facing society in the coming decades. The effects of climate change on natural and human systems are widespread and may be profound, with substantial environmental, economic, and social consequences.

A large number of scientific organizations have come to the conclusion that human activities are increasingly altering the Earth's climate (mainly though increasing concentrations of greenhouse gasses) and add to the effects of natural climate change and variability. These changes need to be set against the long-term pattern of climate change and variability, which is provided by studying the geologic record of climate change.

There is abundant evidence that Earth's climate has changed on various timescales throughout geologic time, and will continue to change in the future. These changes include droughts such as that which caused the Dust Bowl of the 1930's; longer duration events such as the Little Ice Age (a period of cooler temperatures which affected the northern hemisphere between about 1400 and 1900 AD); the glacial-interglacial cycles of the past 2.5 million years; and periods of greater warmth that existed during the Cretaceous and Eocene. With the exception of the past century or two, our knowledge of past climates is based on the geologic record of climate change and the information on past environments obtained from a range of proxy indicators of past climate conditions (especially temperature and precipitation). Understanding the geologic record of climate change is important, because it provides a background against which to assess current and future changes and the means by which the effects of natural climate change and variability and human impacts on climate can be disentangled. Knowledge of past landscape and ecosystem processes improves our ability to forecast the likely effects of future climate changes. In addition, study of the record of climate change allows investigation of the mechanisms of climate change and the forcing factors involved on different timescales.

The Earth Surface Dynamics Program of the USGS addresses these challenges by conducting multidisciplinary studies of past environmental and climatic changes (climate history); process studies that explore the sensitivity of the Earth-surface and associated ecosystems to climate variability; and forecasting of potential future changes and their effects on landscapes, land use, and ecosystems (particularly on public lands).

1.2 The Organizational Context and Role of the Program

1.2.1 Department of the Interior (DOI)

The DOI has responsibilities, conveyed by various legislative authorities, to manage and protect the Nation's living resources. The DOI revised its Strategic Plan in 2003 to emphasize the information base, resource management, and technical assistance for decision making. The DOI Strategic Plan aims to unify scientific knowledge with applications of that knowledge toward resource management through collaboration among scientists and Federal, State, Tribal and non-governmental natural resource managers. The DOI mission promotes informed Resource Protection, Resource Use, and Recreation, with the goal of Serving Communities by advancing knowledge and informing decisions through the application of science. The United States Geological Survey's (USGS) ESD Program supports the DOI Serving Communities Strategic Goal by advancing knowledge through scientific leadership and informing decisions through the application of science (End Outcome Goal SEO.2).

1.2.2. U.S. Geological Survey

The USGS serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life. As the science agency for the Department, the USGS is entrusted to provide unbiased, independent data and information on biology, hydrology, geology, and geography to the DOI and the Nation. The USGS has a primary responsibility to provide high-quality scientific data to the Department and its resource bureaus that manage DOI lands and their associated biological resources. A major institutional strength of USGS is the opportunity to conduct truly interdisciplinary science. The bureau actively seeks to promote scientific undertakings that integrate the bureau's capabilities in biology, geology, mapping, and hydrology on multiple spatial scales.

1.2.3 USGS Geology Discipline (GD) and its Mission

The Geologic Discipline (GD) of the USGS administers all programs under the Geologic Hazards, Resources, and Processes activity, including Earthquake Hazards, Volcano Hazards, National Cooperative Geologic Mapping, Coastal and Marine Geology, Earth Surface Dynamics, Mineral Resources, and Energy Resources. The GD also has program responsibilities for the Global Seismographic Network, landslide hazards, and international activities.

In fiscal year 2005, the GD's appropriated budget for all programs is $249.247 million. In addition to Congressionally appropriated funds, the GD receives reimbursements from other Federal agencies for conducting research. For example, the National Aeronautics and Space Administration supports the GD's Astrogeology program. In turn, the GD offers grants to State and local agencies, universities, and the private sector to undertake earth science investigations. GD scientists also conduct cooperative research with the private sector and international governments through formal agreements.

The GD conducts an integrated mixture of monitoring, research, and assessment activities in support of seven major science goals which address major societal issues involving geologic hazards and disasters, climate variability and change, energy and mineral resources, ecosystem and human health, and ground-water availability (see Geology for a Changing World: A Science Strategy for the Geologic Division of the U.S. Geological Survey, 2000-2010. U.S. Geological Survey Circular 1172, 1998, http://pubs.usgs.gov/circ/c1172/.

The science goals include:

Goal 4: Anticipate the environmental impacts of climate variability. This goal defines a leadership role for the USGS within the U.S. National Global Change Program (now the Climate Change Science Program - CCSP) in carrying out regional- to national-scale syntheses on the following two topics: (1) reconstructions of past climates from terrestrial records and (2) assessments of the potential impacts of climate change or variability.

Goal 5: Establish the geological framework for ecosystem structure and function. This goal includes strategic actions to: (1) determine rates of floral, faunal, and other environmental changes; (2) conduct fundamental research to understand the roles of surface geology, geomorphology, and surficial geologic processes; and (3) Investigate bigeochemical cycles in ecosystems.

Goal 6: Interpret the links between human health and geologic processes

ESDP activities address all these goals, with an emphasis on Goals 4 and 5.

2. EARTH SURFACE DYNAMICS PROGRAM

2.1 Program History

The Earth Surface Dynamics Program (ESDP) was initiated in 1997 and grew out of the activities and strengths of the Global Change and Climate History Program (GCCH), which was the Geologic Division's component of the USGS effort in support of the U.S. Global Change Research Program (USGCRP). The USGCRP is a cooperative of 12 federal agencies conducting global change research founded in 1991 and was authorized by the U.S. Global Change Research Program Act of 1990 [Public Law 101-606(11/16/90) 104 Stat. 3096-3104.

In 2002, the Climate Change Science Program (CCSP) was formed as a result of the Climate Change Research Initiative (CCRI) of President G.W. Bush, designed to identify the scientific information that can be developed to assist the evaluation of optimal strategies to address global change risks. The CCSP incorporates the U.S. Global Change Research Program (USGCRP). The CCSP developed a strategic plan (CCSP, 2003) which articulates a vision for federal climate change research. The CCSP strategic plan identifies 5 major goals (Box 1).

Box 1: CCSP Goals

1. Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change
2. Improve quantification of the forces bringing about changes in the Earth's climate and related systems
3. Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future.
4. Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes
5. Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

ESD seeks to expand the scope of research previously supported by the GCCH program in order to be more responsive to the science needs of DOI resource management bureaus, while still providing important data and information to the CCSP and the national and international scientific communities.

2.2 Current Program

The current range of research activities supported by ESDP includes projects that: (1) conduct studies of past climates and environments; (2) investigate the effects of past and present climate change and variability on landscapes and ecosystems; (3) conduct studies of the processes involved in landscape change; and (4) forecast the effects of climate change and variability on landscapes and ecosystems. In many cases, individual projects may include elements of all the above (Table 1).

Investigations of climate and environmental history are conducted in a wide range of locations from SE and Central Alaska, through the intermountain west to the Gulf of Mexico and estuaries in the mid Atlantic region. This ensures that the program provides policy relevant information on past climatic conditions for a wide range of biomes and landscapes. Projects that study the impact of climate change and variability on landscapes and ecosystems range in location from the North Slope of Alaska to the southwestern USA. Many of these projects provide information that directly supports land use and land management decisions. Examples include information on historic trends in land use, land cover, and sedimentation in the Chesapeake Bay watershed and the influence of land use and climate variability on wind erosion on the Colorado Plateau.

Table 1: Current Project Emphasis

FY 05 Projects	Program components addressed			
	1	**2**	**3**	**4**
Alaska Quaternary Climate History	x	x		
Holocene Climate of the Pacific Coasts	x	x		

Cryospheric Studies		x	x	x
Fate of Carbon in Alaskan Landscapes		x	x	x
Surficial Geologic Mapping in the Southwest		x	x	x
Eolian History of North America	x	x		
ROMA: River Observatories for Management Applications	x	x	x	
Gulf of Mexico Climate and Environmental History	x			
Impact of Climate Change and Land Use on American drylands		x	x	x
Western Lake/Catchment Systems	x	x		
Global Dust		x	x	
Appalachian Blue Ridge Landscape	x	x		
Climate Change, Land Use, and Environmental Sensitivity (CLUES)		x	x	x
Atlantic Estuaries	x	x		
Glacier Studies		x	x	
Global Warming Analysis (USGS-NSF)	x			
Carbon Cycling in the Lower Mississippi Basin		x	x	
Geology of National Parks: National Park Service Support		x	x	
Abrupt climate change	x	x		

Table 2 lists the projects supported by the ESDP in FY2005 and their relationship to CCSP strategic goals.

Funding levels for the ESD program have fluctuated in recent years around a level of approximately $10 million, with a flat to slightly declining overall budget allocation. Figure 1 shows the overall program funding and its distribution amongst types of support. Table 3 documents the funding levels for projects supported in FY05.

Table 2: Projects supported by the ESDP in FY2005 and their relationship to CCSP strategic goals.

FY 05 Projects	CCSP Goals Addressed				
	1	**2**	**3**	**4**	**5**
Alaska Quaternary Climate History	x			x	
Holocene Climate of the Pacific Coasts	x			x	
Cryospheric Studies	x	x		x	
Fate of Carbon in Alaskan Landscapes	x	x		x	
Surficial Geologic Mapping in the Southwest	x			x	
Eolian History of North America	x			x	
ROMA: River Observatories for Management Applications	x			x	
Gulf of Mexico Climate and Environmental History	x			x	
Impact of Climate Change and Land Use on the Southwest U.S.	x			x	x
Western Lake/Catchment Systems	x			x	
Global Dust	x			x	
Appalachian Blue Ridge Landscape	x			x	
Climate Change, Land Use, and Environmental Sensitivity (CLUES)	x		x	x	x
Atlantic Estuaries	x			x	
Glacier Studies	x			x	
Global Warming Analysis (USGS-NSF)	x			x	
Carbon Cycling in the Lower Mississippi Basin				x	
Geology of National Parks: National Park Service Support				x	
Abrupt climate change	x			x	

The majority of ESD-funded projects are conducted by project leaders belonging to the Earth Surface Processes (ESP) teams based in Reston, VA, and Denver, CO. One project is led from the Western Region ESP team in Menlo Park, CA, while two other projects are administered through the Volcanic Hazards Team. Other projects are based in the Florida Integrated Science Center (FISC), and the Coastal and Marine Geology Team at Woods Hole.

Project staff members are mostly from the Geologic Discipline, but also include members of the Geography, Biology, and Water Resources Disciplines.

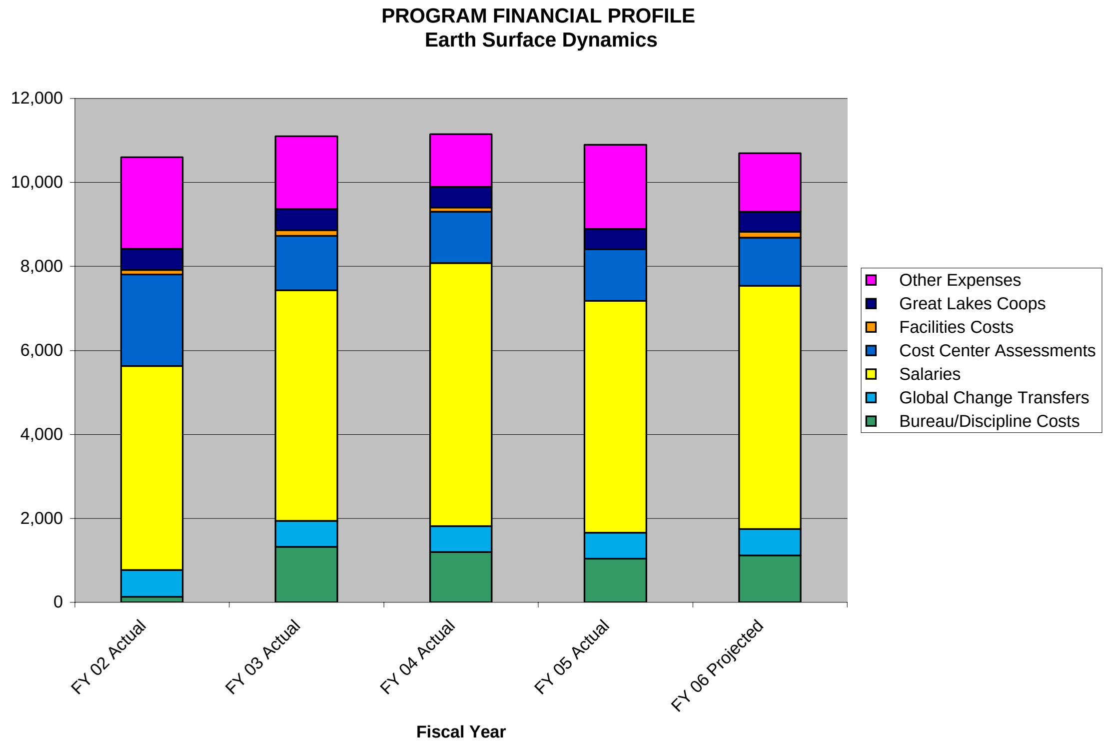

Figure 1: Program financial profile in recent years

2.3 Recent program accomplishments

The ESDP supports a great variety of projects. Below are some examples of recent accomplishments of ESD-supported projects taken from the FY05 and FY06 Greenbooks that provide a sense of the diversity and strength of the program.

Monitoring Climate Change and Variability in Alaska – The polar regions play a critical role in controlling global-scale atmospheric dynamics. All model simulations of global change show a large amplification in the polar regions. Thus, the polar regions are the most sensitive areas for detecting global change, regardless of cause. The Arctic is particularly vulnerable to climate change because of the large temperature changes that occur there and the disruption caused by melting/freezing of ice and permafrost. In addition, the polar regions have the greatest potential for causing abrupt global-scale climate changes through instabilities and feedbacks involving the cryosphere and ocean circulation.

Ongoing studies by ESDP-supported researchers in collaboration with the National Science Foundation, the BLM, and the FWS are monitoring the state of permafrost in northern Alaska. Investigations focus on the active layer, the surface layer that freezes and thaws annually in cold regions and the thermal state of the underlying permafrost. These observations form part of the Global Terrestrial Network for Permafrost (GTN-P), a component of Global Climate Observing System (GCOS).

Table 3: FY05 Project funding levels

Project Title	FY05 $
Alaska Quaternary Climate History	420,000
Holocene Climate of the Pacific Coasts	497,948
Cryospheric Studies	240,000
Fate of Carbon in Alaskan Landscapes	333,843
Surficial Geologic Mapping in the Southwest	240,000
Eolian History of North America	475,391
ROMA: River Observatories for Management Applications	230,000
Gulf of Mexico Climate and Environmental History	460,000
Impact of Climate Change and Land Use on North American drylands	1,431,412
Western Lake/Catchment Systems	900,000
Global Dust	640,000
Appalachian Blue Ridge Landscape	190,000
Climate Change, Land Use, and Environmental Sensitivity (CLUES)	558,047
Atlantic Estuaries	192,000
Glacier Studies	705,000
Global Warming Analysis (USGS-NSF)	244,000
Carbon Cycling in the Lower Mississippi Basin	270,000
Geology of National Parks: National Park Service Support	70,000
CR Isotopic/Geochronology Core Operations, Lab Support	40,000
Radiocarbon Dating	197,000
Tephrochronology Laboratory	16,010
Internet Information Dissemination for the Earth Surface Dynamics Program	70,902
Abrupt Climate Change, Eastern United States	35,000
Earth Surface Dynamics Program Office	346,362

Active layer monitoring utilizes 30 stations in Alaska, with 9 stations located on DOI lands in the National Petroleum Reserve-Alaska (NPRA) and the Alaska National Wildlife Refuge (ANWR). These stations measure meteorological conditions and permafrost temperatures to detect and monitor contemporary climate variability in this region for a baseline against which to judge future change and assist in evaluating management options. The 21-element GTN-P borehole array is located within the NPRA. This is the largest array of deep boreholes in the world available for monitoring the thermal state of deep permafrost and provides critical data for determining the terrestrial response to climate change in the Arctic. Initial results from this network indicate that the temperatures have risen by 2-4 degrees in the past decade.

Comparing Erosion Rates in Natural and Human-affected Conditions – The recent geologic record of sediments deposited in estuaries provides important data on erosion and sedimentation rates in natural (pre-colonial) and modern conditions. These data provide a baseline against which to assess the impacts of changes in climate land use on sedimentation and water quality in key ecosystems, including the Chesapeake Bay. If trends can be identified, that information can be used to make recommendations for the future. Recent investigations of sediment cores in the Chesapeake Bay area by ESDP-supported scientists document the impact of forest clearance for agriculture, timber, and urbanization on water quality over the past 300 years. Peak timber harvesting in the period 1880-1910 increased sedimentation two to four times over pre-colonial rates. Water quality changes associated with increased urbanization and agricultural nutrient loading occurred after 1950. The Susquehanna River is the largest single contributor of water and sediment to Chesapeake Bay. Ongoing investigations in the watershed of the Susquehanna River are providing information on long-term rates of erosion and sediment delivery to the bay, as well as the impact of land use practices on short-term erosion and sedimentation, which critically impact bay fisheries and shellfish industries, wildlife habitats, and recreation. These and other studies provide the background data necessary to guide efforts to mitigate changes in water quality in this and other estuaries.

Effects of Urbanization on River Systems — The ESDP has recently completed a study of the effects of increasing urbanization on the Las Vegas Wash, which has been transformed from an ephemeral stream receiving water only after a storm to a perennial stream, fed mostly by discharge of effluent from wastewater treatment plants. Population in the Las Vegas, NV, metropolitan area has increased by a factor of six between 1970 and 2000. During this period, runoff in the wash increased four fold and as much as 8.6 million cubic yards of sediment were eroded from the floodplain and deposited in a delta in Lake Mead over a 15-year period. Flood magnitude and frequency also increased, as a result of increased runoff from streets and paved areas. Stream erosion and deposition caused major damage to infrastructure in the area and $87-99 million of ongoing and planned engineering structures have been required to stabilize the wash. These studies indicate the magnitude of changes in river channels that can take place as a result of human-caused changes in the environment. Data from this study are being used by State and local governments to plan and execute engineering measures to mitigate the effects of these changes.

Studies of Past Vegetation and Climate — Scientists supported by the ESDP continue to provide important data regarding the characteristics and timing of past changes in climate and vegetation in ecologically sensitive areas, including southeast Alaska, northern California, and the Appalachians. These studies are being used by land management agencies including the U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (FWS), and National Park Service (NPS) to develop management plans for these areas, in addition to supporting CCSP goals.

USGS researchers, in collaboration with colleagues from academia, are providing high-resolution records of climate change and variability over the past 10,000 years for southeastern Alaska, northern and central California, the Great Basin, the northern Rocky Mountains, and Chesapeake Bay. These records document the natural long and short variability of the climate system against which to assess present climate trends, and develop effective strategies to manage resources in the face of climate variability. For example, a recent record obtained from coastal northern California indicates that the present coastal temperate rainforest was established 5,000 to 3,500 years ago. In the Gulf of Mexico, detailed records of climate variability indicate the persistence of century-scale variations in climate, possibly resulting from changes in solar output. In the Shenandoah

National Park, studies of past vegetation indicate frequent and rapid changes in species composition in response to global climate changes. Many forest types identified suggest regional climates cooler than the present. These studies are helping the NPS develop plans to manage threatened and endangered species of plants.

In southeast Alaska, USGS scientists, working in collaboration with other Federal agencies such as the U.S. Forest Service (USFS), have mapped the extent of glaciers at the end of the last ice age in relation to sea level and thereby identified refugia from which animals and plants recolonized the land left bare as the glaciers retreated. This study has also identified pathways by which early humans could have migrated south. Documenting the nature and magnitude of past climate change and variability is essential for understanding the present and future state of the climate system.

***Soil Carbon Database for the Mississippi River Basin* —** In order to better understand the dynamics of the carbon cycle in the United States, USGS scientists have recently completed a site-specific database for soil organic carbon for much of the Mississippi River basin. The database includes soil-carbon and related data for 9,215 pedons (soil columns) that were described and sampled by various agencies; e.g., U.S. Department of Agriculture (USDA), National Resources Conservation Service; State soil surveys, and universities, between 1928 and 1995. The database was originally developed for use in USGS terrestrial-carbon cycling studies in the Mississippi River basin as part of the USGCRP, Global Carbon Cycle program element. The USGS studies were designed to characterize systems across spatial scales ranging from hill slopes to small watersheds to the large-river systems that comprise the Mississippi River basin. These studies included: (1) measurement of soil organic carbon (SOC) erosion, deposition, and transformation at the field scale; (2) measurement and modeling of SOC and sediment transport at the small-watershed scale, and (3) measurement, modeling, and statistical analysis of environmental controls on the geographic distribution of SOC at the large-basin scale.

This database is a major USGS contribution to the CCSP and also is being used by FWS and National Oceanic and Atmospheric Administration (NOAA) to plan and execute strategies for carbon sequestration

Terrestrial records of drought - One aspect of climate change of particular concern in the western U.S. is the potential increase in areal extent and severity of droughts. The consequences of prolonged droughts in this region are particularly severe because water resources are fully allocated to support agricultural, industrial, residential, and recreational uses. Instrumental records of climate are much too short to fully assess the natural range of climate variability. USGS scientists are using the geochemical, mineralogical, and biological records from lake sediments to extend the history of climate change and to assess the effects of such change on the land surface and hydrologic systems. USGS studies of Bear Lake (Utah/Idaho) indicate that lake levels throughout much of the last 10,000 years were far below lake levels during the past 150 years. This finding contributes to a growing body of evidence that the 20th century was anomalously wet and indicates that the growing population of the region may have to find ways to cope with less water than has been historically available. Similarly, long records are needed to fully understand the potential impacts of climate change on the land surface. USGS studies of Crevice Lake in Yellowstone National Park are providing new understanding about the complex relations among precipitation, vegetation, fire history, and erosion, thereby providing information vital to formulating plans for managing these lands under changing climatic conditions.

***Impacts of Drought on Stabilized Sand Dunes* —** Much of the area of the Navajo nation in northeastern Arizona and adjacent areas of New Mexico, Colorado, and Utah is covered by vegetated sand dunes. These dunes are very sensitive to climate variability and change, including the current period of drought, resulting in remobilization of dune areas and consequent impacts on infrastructure and agriculture. USGS scientists working closely with the Navajo Nation have compiled maps of the sand deposits at a scale of 1:50,000. These maps are combined with information on the spatial variation in rainfall and potential evapotranspiration over the period of record and recent drought years to provide an assessment of landscapes susceptibility to climate change and variability in the region. These products are being used by the Navajo Nation to plan response to and mitigate the effects of the current severe drought; as well as by the Navajo-Hopi lands commission to develop grazing guidelines for the Navajo partition lands.

3. FUTURE CHALLENGES AND DIRECTIONS

3.1 National Perspective

Many observations of natural phenomena suggest that we are living in a time of rapidly changing climates. Instrumental records indicate a rapid rise in northern hemisphere temperatures since the early 1900's and this appears to be manifested today in a shrinking Arctic sea cover, melting of permafrost in Alaska and elsewhere, earlier blooming of plants, changes to the timing of spring melting of snow and ice, and many other changes in the Earth system.

Understanding the geologic record of climate change is important, because it provides a background against which to assess current and future changes (Alverson et al., 2003). Knowledge of past ecosystem processes improves our ability to forecast the likely effects of future climate changes. In addition, study of the record of climate change allows investigation of the mechanisms of climate change and the forcing factors involved on different timescales. The importance of the paleoclimatic record is increasingly recognized. For example, the IPCC 4th Assessment Report will include a paleoclimate chapter for the first time. The CCSP Strategic Plan recognizes the need for improved paleoclimate data bases and modeling for a variety of purposes, including identification of the mechanism and causes of abrupt climate changes and documentation of climate extremes. Although the USGS is a relatively small contributor to Federal climate change research efforts (1.7 % of the total, FY04), it is the primary provider of data on the geologic record of climate change.

A significant component of the ESDP involves study of the effects of climate change on ecosystems and landscapes. For example, average global temperatures are hypothesized to increase from 1 to 5°C in the next century, with the greatest increases occurring in the mid- to high-latitudes of the northern hemisphere. The rate of temperature increase is unprecedented in the geologic and instrumental record and is likely to exacerbate existing stresses on ecosystems from land use change, invasive species and extinctions, possibly leading to a non-linear response of ecosystems to climate change. The effects of climate change will vary regionally and may include increased magnitude and frequency of extreme events (floods, droughts), melting of permafrost, ice sheets and glaciers, sea level rise, and changes in vegetation type and structure leading to habitat loss and/or change in the spatial distribution of biomes and loss of biodiversity. As a result the US Fish and Wildlife Service has identified climate change as one of its most pressing future challenges. Climate change will impact the mission of agencies such as the Fish and Wildlife Service by increasing the uncertainty around the decision making process. If home ranges, distributions or migratory patterns of both plant and animals change relatively quickly, it will be difficult to provide adequate conservation measures or habitat protections.. Management will become increasingly difficult, as the land base and water base available for natural redistribution of species has diminished. For example, climate change may significantly reduce the future usefulness of refuges and protected coastal areas as sea levels rise and salt water intrudes.

Although it is important to document the effects of climate change on landscapes and ecosystems and to understand the processes involved, modeling and forecasting of the effects of climate change on landscapes and ecosystems is needed to provide information that can be used by land managers and other decision makers. These activities will form an increasingly important part of the ESDP in the future.

In their discussion in *Future Roles and Opportunities for the US Geological Survey* (NRC, 2001), the National Research Council stated that " global climate change offers an array of scientific and societal challenges that fall within the expertise and mandate of the agency". They identified possible roles for the USGS that include:

"Documentation of the anthropogenic influences on climate via detailed records of climate change, which provide information on the degree of past climate variability and the undisturbed climate state"

"Understanding of the multiple causes of climate change, including human changes in land use and land cover"

"Effects of climate change on geologic hazards, including magnitude and frequency of extreme events (e.g. floods)"

"Determination of societal sensitivity and vulnerability to climate change"

"Enhanced contribution to the understanding of global geochemical cycles, especially the carbon cycle and hydrologic cycle, and their sensitivity to and influence on climate change"

"Greater USGS participation in the global change research community [that] *would help to widen the discussion beyond the current focus on temperature changes and warming to include changes in the hydrologic cycle, vegetation, and biota"*

The above opportunities provide much of the context for the development of the program goals and objectives set out in section 4.2. When coupled with the research needs set out in the Climate Change Science Program Strategic Plan (Box 1), they define the following key areas for future program activities:

- Document and understand the temporal and spatial scales of climate variability
- Document and understand the effects of climate change on ecosystems and landscapes – especially in the Arctic, the desert Southwest, the upper Colorado River, and the eastern mountains and coastal plains
- Develop regional and national syntheses of paleoclimatic data and provide data-model comparisons
- Anticipate the state of ecosystems and landscapes in a range of plausible future climate changes

4. PROGRAM DIRECTIONS FOR THE FUTURE

4.1 Scientific Vision

The Earth Surface Dynamics Program has identified the following scientific vision to guide activities over the next 5 to 10 years:

To be the primary provider of scientific information on past, present, and future climates and their effects on earth and human systems to fulfill the mission of the US Geological Survey.

4.2 5-year program goals, objectives, and strategies

The ESDP has identified the following goals, objectives, and strategies for its activities over the next 5 years. These will guide funding of projects by the program as well as the conduct of investigations by individual projects and tasks. Project leaders are requested to ensure that project goals, objectives, and research strategies are compatible with these goals, especially when preparing work plans. Table 4 shows the relationship between current projects and the goals and objectives set out below, and indicates the areas where future program growth will occur.

Program Goal 1: Understand climatic and environmental change and variability on different time scales.

Program Objective 1.1: Construct well-resolved records of climate and environmental changes with sufficient temporal and geographic coverage to document and understand patterns of climate variability.

Strategy: Investigate past changes in temperature and precipitation in selected terrestrial settings (e.g., wetlands, floodplains, deserts, lake basins) using paleoenvironmental proxies (such as pollen, lacustrine diatoms, isotopic indicators, tree rings); and in cryospheric settings using geophysical inverse methods

Strategy: Investigate past changes in surface- and bottom-water temperatures, as well as in salinity in estuaries and marine sites, using paleoenvironmental proxies (such as ostracodes, foraminifera, diatoms, dinoflagellate cysts, isotopic indicators).

Strategy: Determine and describe modes of climate variability (such as NAM, NAO, ENSO, PDO) over time scales of seasons to hundreds of thousands of years in different environmental settings.

Program Objective 1.2*:* Document climate variability over timescales ranging from seasons to hundreds of thousands of years.

Strategy: Monitor climatic parameters in selected regions using instrumental arrays

Strategy: Conduct statistical analyses of climatic parameters over various spatial and temporal scales

Program Objective 1.3: Document rates and degree of change associated with intervals of abrupt climate change.

Strategy: Identify terrestrial and marine sites that contain well-resolved records of abrupt climate change at various times (such as 8.2 ka event, Younger Dryas).

Strategy: Investigate rates and degree of climatic and environmental change associated with abrupt events using paleoenvironmental proxies.

Strategy: Evaluate synchroneity and magnitude of change of climate parameters (such as temperature, precipitation) during intervals of abrupt climate change at sites throughout North America and elsewhere.

Program Objective 1.4: Understand the geographic and temporal patterns associated with the interactions among the atmosphere, cryosphere, land surface, and ocean under different modes of climatic variability and change on time scales ranging from years to millennia.

Strategy: Assemble broad spatial networks of well-dated materials to document how changes in Pacific Ocean sea-surface temperatures result in ENSO-related changes in moisture availability and geographic patterning in North America.

Strategy: Assemble broad spatial networks of well-dated sites to document how changes in the thermohaline circulation of the North Atlantic Ocean affect global climatic regimes on land, especially during the Younger Dryas period.

Program Objective 1.5: Evaluate uncertainty of reconstructions of past climates.

Strategy: Use inverse theory concepts to better establish the full range of climate conditions (states) consistent with paleoenvironmental observations.

Strategy: Develop modern calibration datasets to determine the influence of climate states on paleoenvironmental proxies (for example, modern pollen assemblages, isotopic composition of micro-fossil assemblages)

Program Objective 1.6: Determine the sensitivity of the climate system to external forcing.

Strategy: Use formal inverse methods to reconstruct the magnitude of past climate changes from physical and/or chemical data sets that can be mathematically modeled.

Program Objective 1.7: Determine the sensitivity of different models to changes in atmospheric chemistry and external forcing.

Strategy: Assemble paleoenvironmental data sets to be used for regional climate model or AOGCM input to test climate model performance.

Strategy: Work with the global data-model community to develop consistently applied methods to assemble and interpret spatial and temporal arrays of paleoenvironmental data, such as fossil pollen, plant macrofossil, isotopic, glacial, and lake-status data.

Links to Other Programs: This goal will link to all programs in USGS that are concerned with climate change including Priority Ecosystem Sciences (PES). In the Geologic Discipline there are links to the NCGM, and CMG programs.

Links to CCSP Goals: This goal links to CCSP Goal 1 (Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change)

Partners and Customers: Federal land management agencies (e.g. USFWS, National Park Service, US Forest Service, Bureau of Land Management), CCSP, NOAA, National Science Foundation, universities, non-governmental organizations (NGO's) such as the Chesapeake Bay Program.

Products, Outcomes, and Measures: ESDP-funded scientists produce numerous articles that are published in peer-reviewed journals, presentations at professional science symposia, and recommendations for natural resource managers / decision makers.

The outcome of this goal is improved knowledge of the spatial and temporal patterns of past climate change.

Performance measures will be the number of systematic analyses and reports delivered to customers and databases developed and maintained.

Program Goal 2: Determine the effects of climate change and variability on terrestrial and marine systems on different time scales

Program Objective 2.1: Determine and describe changes to the Nation's lands under past and current changes in climate and human activity.

Strategy: Conduct field and laboratory research to document the response of climatically sensitive landscapes, geomorphic systems, and ecosystems to climate change and variability (e.g., in polar regions, drylands, forests, grasslands, lakes, rivers, and wetlands).

Strategy: Conduct field and laboratory research to distinguish between the effects of natural earth-system change and changes caused by human activity and to understand how interactions among natural and human-related processes affect landscapes and ecosystems.

Strategy: Conduct field and laboratory research to establish baseline levels of variability in the structure and function of terrestrial ecosystems.

Strategy: Monitor and measure landscape responses to climate variability and change in selected regions using ground-based instrumentation and remote sensing techniques.

Strategy: Determine the sensitivity of landscape components and processes in arid regions to changes in specific climate parameters (temperature, precipitation, wind) using a combination of landscape and atmospheric models.

Program Objective 2.2: Determine and describe changes in the Nation's estuaries and near-coastal environments under past and current changes in climate and human activity

Strategy: Conduct field and laboratory research to document the response of marine and estuarine ecosystems to climate variability

Strategy: Conduct field and laboratory research to document the influence of climate-induced sea-level change on estuarine and coastal environments

Strategy: Conduct field and laboratory research to establish baseline levels of variability in the structure and function in estuarine and near-coastal ecosystems.

Strategy: Determine the sensitivity of estuarine and marine settings to changes in specific climate parameters (precipitation, salinity, temperature, wind) using a combination of ocean and atmospheric models.

Program Objective 2.3: Determine and describe the effects of climate change and variability on the carbon cycle as it relates to surficial processes, land use, and vegetation

Strategy: Conduct field and laboratory research on carbon cycle dynamics of selected ecosystems, such as wetlands, boreal forests, permafrost regions, and river systems.

Strategy: Model the effects of climate on the carbon cycle as it relates to surficial processes, land use, and vegetation

Strategy: Determine the sensitivity of greenhouse-gas exchanges between the land and the atmosphere to changes in specific climate parameters using biogeochemical models.

Strategy: Monitor and assess changes in carbon cycling that result from changes in the active layer and underlying permafrost influenced by climate change and variability.

Program Objective 2.4: Determine and describe the effects of changes in climate on plant-community distribution from reconstructions of past and current vegetation-climate relations

Strategy: Conduct field and laboratory research to determine the distribution of plant communities at times during the Quaternary and their relations to past climate.

Strategy: Model and map the distribution of ecosystems, compatible with shifts in regimes of temperature and precipitation, along with changing atmospheric CO_2 content.

Strategy: Determine the sensitivity of vegetation to changes in specific climate and earth-surface parameters (temperature, CO_2, soil moisture) using a combination of vegetation and atmospheric models.

Program Objective 2.5: Determine and describe the effects of recent climatic change and variability on the cryosphere

Strategy: Monitor the response of the active layer and the underlying permafrost to current climate change and variability using instrument arrays.

Strategy: Determine the response of permafrost to changes in specific climate parameters using a combination of ground temperature, landscape, and atmospheric models.

Links to Other Programs: This goal will link to all programs in USGS that are concerned with climate change including PES.

Links to CCSP Goals: This goal links to CCSP goal 4 (Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes)

Partners and Customers: Federal land management agencies (e.g. USFWS, National Park Service, US Forest Service, Bureau of Land Management), CCSP, National Science Foundation, NOAA, universities, non-governmental organizations (NGO's) such as the Chesapeake Bay Program and The Nature Conservancy.

Products, Outcomes, and Measures: ESDP-funded scientists produce numerous articles that are published in peer-reviewed journals, presentations at professional science symposia, and recommendations for natural resource managers / decision makers.

The outcomes of this goal include a better understanding of the effects of climate change on landscapes and ecosystems and therefore an enhanced ability to forecast the effects of climate change on landscapes and ecosystems.

Performance measures will be the number of systematic analyses and reports delivered to customers and the number and size of databases developed and maintained.

Program Goal 3: Develop a fundamental understanding of processes that govern interactions among climate, earth surface processes, and marine and terrestrial ecosystems

Program Objective 3.1: Determine and describe the biogeochemical processes, including feedbacks, associated with ecosystem changes

Strategy: Conduct field and laboratory studies over different spatial scales to understand biogeochemical interactions among environmental variables (such as climatic, ecologic, biologic, hydrologic, and geomorphic processes)

Strategy: Determine and document biogeochemical signatures of ecosystem change.

Strategy: Determine the influence of earth-surface processes on greenhouse gas emissions using a variety of process-based studies and models

Strategy: Use mathematical models to improve our understanding of interactions and feedbacks in biogeochemical processes and greenhouse gas emissions

Program Objective 3.2: Understand the interactions between climatic changes and changes in land cover and land use and understand the effects of these interactions on natural resources and societal needs on regional to continental scales over the past 20,000 years.

Strategy: Compile and analyze paleoecological records to determine past changes in land cover related to the interactions of climatic changes, disturbance regimes, and human activities since the Last Glacial Maximum.

Strategy: Compile and analyze historic records and paleoecological data to determine the land cover changes related to the interactions of climatic variability, disturbance regimes, and historic land use.

Strategy: Monitor and measure geomorphic and biogeochemical effects of natural and anthropogenic disturbance and climatic variability in selected areas.

Strategy: Develop models that describe the effects of the interactions among climatic change, climatic variability, disturbance regimes, and land use on land cover, ecosystems, and landscapes.

Program Objective 3.3: Identify critical thresholds in geomorphic and biogeochemical processes in selected environments

Strategy: Conduct field studies to document interactions among environmental variables that produce change in system state

Strategy: Use mathematical models to improve our understanding of critical thresholds

Program Objective 3.4: Quantify rates of change in landscapes and ecosystems in response to climate and anthropogenic changes

Strategy: Use geochronology and field studies to determine rates of erosion and deposition in selected systems

Strategy: Use paleoecological reconstructions and geochronology to establish timing and rates of ecosystem change

Strategy: Use mathematical models to understand landscape evolution

Program Objective 3.5: Determine and describe the human health effects that result from interactions among climate, disturbance, as well as surficial processes and sediments

Strategy: Conduct research in selected areas to understand the environments of pathogens, contaminants, and metals in soils and the processes that govern their transport to human populations

Links to Other Programs: This goal will link to all programs in USGS that are concerned with climate change including PES. In the Geologic Discipline there are links to the NCGMP and CMGP.

Links to CCSP Goals: This goal links to CCSP goal 4 (Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes)

Partners and Customers: Other Federal land management agencies (e.g. USFWS, National Park Service, US Forest Service, Bureau of Land Management), CCSP, National Science Foundation, NOAA, NIH, universities, non-governmental organizations (NGO's) such as the Chesapeake Bay Program and The Nature Conservancy.

Products, Outcomes, and Measures: ESDP-funded scientists produce numerous articles that are published in peer-reviewed journals, presentations at professional science symposia, and recommendations for natural resource managers / decision makers.

The outcome of this goal is improved knowledge of the spatial and temporal patterns of past climate change.

Performance measures will be the number of systematic analyses and reports delivered to customers and databases developed and maintained.

Program Goal 4: Anticipate the effects of climate change and variability on natural and human systems under a range of plausible future climate scenarios.

Program Objective 4.1: Use numerical models to assess the potential impact of future climate scenarios on the land surface in critical regions (e.g. coastal zones, arctic and boreal Alaska, arid regions, mountains) at adequate spatial scales to support management and policy decisions.

Strategy: Assess how selected ecosystems may change during the next 100 years in response to future climate scenarios using ecosystem models including those driven by AOGCM and/or high-resolution RCM output.

Strategy: Assess how rates of geomorphic processes may change over the next 100 years in response to future climate scenarios using coupled landscape/ecosystem models including those driven by AOGCM and/or high-resolution RCM output.

Strategy: Assess how various landscape components, such as lakes, wetlands, sand dunes, and drainage systems may change in response to future climate scenarios using coupled landscape/ecosystem models driven by AOGCM and/or high-resolution RCM output.

Program Objective 4.2: Assess the effects of plausible future climate scenarios and landscape change on human activities and health in selected regions (e.g., coastal zones, arctic and boreal Alaska, arid regions, mountains)

Strategy: Build and foster partnerships with other federal agencies and state and local governments to apply modeling results to assess impacts of climate change on human activities and health

Links to Other Programs: This goal will link to all programs in USGS that are concerned with climate change including PES, and includes NCGMP and CMGP in the Geologic Discipline.

Links to CCSP Goals: This goal links to CCSP Goal 3 (Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future); Goal 4 (Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes), and Goal 5 (Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change).

Partners and Customers: Federal land management agencies (e.g. USFWS, National Park Service, US Forest Service, Bureau of Land Management) , CCSP, National Science Foundation, NIH, universities non-governmental organizations (NGO's) such as the Chesapeake Bay Program and The Nature Conservancy.

Products, Outcomes, and Measures: ESDP-funded scientists produce numerous articles that are published in peer-reviewed journals, presentations at professional science symposia, and recommendations for natural resource managers / decision makers.

The outcomes of this goal are: (1) Enhanced ability to forecast the effects of climate change on landscapes and ecosystems; and wider and more frequent use of data and models developed by ESDP in land and resource management decisions and by the scientific community

Performance measures will be the number of systematic analyses and reports delivered to customers and the number of formal workshops and training delivered to customers

5. PERFORMANCE MEASURES

ESDP has a number of measures in support of the DOI Strategic Plan and in FY2006 will be subject to the OMB PART process.

The DOI Strategic Plan measures addressed by ESDP are summarized in Table 4.

Table 4: ESDP performance measures in DOI Strategic Plan

End Outcome Goal: SEO.2. Advance knowledge through scientific leadership and inform decisions through the application of science.

Measure	ESDP Goals
Research: Soundness of methodology, accuracy, and reliability of science	*1,2,3,4*
Inform decisions through the application of science: Improved access to needed science information	*1,2,3,4*
Inform decisions through the application of science: Stakeholders reporting that information helped achieve goal	*1,2,3,4*

In addition, ESDP has a number of measures to satisfy GPRA reporting requirements (Table 5).

Table 5: ESDP GPRA Goals and Measures.

Measure	ESDP Goals
# of annual gigabytes collected	1,2,3
# of cumulative gigabytes managed	1,2,3
# of systematic analyses and investigations delivered to customers	1,2,3,4
# of formal workshops or training provided to customers (instances/issues/events)	1,2,3,4

6. PROGRAM REVIEW

To ensure that the ESDP continues to serve its stakeholders and partners, remain responsive to national and international scientific challenges, and improve and adapt program activities, the program seeks input in various ways including, but not limited to: (1) interactions with colleagues at scientific meetings; (2) participation in CCSP Interagency Working Groups; (3) sponsorship of sessions at scientific meetings; (4) Targeted workshops; and (5) direct contact with sister DOI Bureaus and other Federal, state, and local government agencies and NGO's. Members of the ESDP sit on the governing committees of a number of national and international scientific organizations, including AGU (American Geophysical Union), GSA (Geological Society of America), PMIP (Paleoclimate Modeling Intercomparsion Project), and AMQUA (American Quaternary Association).

Within the USGS, the Program Coordinator works with project leaders, team chief scientists, regional science staff, and program coordinators in the Geologic Discipline and elsewhere to define project funding targets and the scope of work for each fiscal year. These are listed in the GD Annual Science Plan, annual project work plans and budgets, and in annual Federal budget justifications. Projects are reviewed annually for compliance with Program goals and objectives and to ensure that they satisfy all internal and external priorities. All new projects undergo review by Program and Regional managers and scientists and existing projects are periodically peer-reviewed for performance and effectiveness (approximately every 5 years).

The ESDP Program Council is chaired by the program coordinator and consists of an annually-rotating group of 6 USGS scientists and one external member. The Program Council reviews all projects on an annual basis to ensure progress on project goals and products, as well as compliance with Program goals. Project plans are modified to take account of the comments and suggestions of this group.

7. EXPERTISE AND CAPABILITIES

The ESDP currently can call upon a broad range of expertise to conduct multidisciplinary research in these areas, including expertise in geology (especially sedimentology and Quaternary stratigraphy), geomorphology, ecology, hydrology, paleontology, palynology, geochronology, climatology, low-temperature and isotope geochemistry, remote sensing, GIS, surficial geologic mapping, numerical modeling, and scientific visualization. The current staff supported by the Program includes many individuals with unique experience and expertise in major areas of Quaternary science, including studies of ostracodes, pollen, aeolian sediments, marine diatoms, monitoring of permafrost and desert surface processes, and geomorphology, as well as regional expertise in reconstructing past environments.

A major concern for the ESDP over the next 5 years and beyond is the loss of knowledge, expertise, and experience through retirement of long-established senior scientists with expertise in fields critical to program goals (see above). Many of these people are national or world leaders in their fields. In 5 years time, it is likely that the Program will have lost at least 4 project leaders, and four or more senior scientists with skills directly relevant to program goals. In 10 years, it is likely that the ESDP will have lost most of its current project leaders by retirement. Unless these people are replaced, the program will no longer have the staff needed to carry out its mission and goals.

Key areas for new or augmented program activities in the next 5 years are: (1) modeling of the response of landscapes and ecosystems to climate change and variability; (2) detailed studies of landscape processes (e.g. biogeochemical cycles, erosion and deposition); and (3) synthesis of data sets for paleoclimate analysis and modeling.

New positions that will be needed in the next 5 years (as a minimum):

- Paleoclimate modeler (2 positions)
- Quaternary paleoecology and paleolimnology (2 positions)
- Quantitative geomorphology (2 positions)
- Biogeochemical modeling (1 position)
- Quaternary geochronology (1 position)

REFERENCES CITED

Alverson, K.D., Bradley, R.S. and Pedersen, T.F. (Editors), 2003. Paleoclimate, Global Change, and the Future. Springer, Berlin, Heidelburg, New York, 220 pp.

Climate Change Science Program and the Subcommittee on Global Change Research, 2003, Strategic Plan for the U.S. Climate Change Science Program, U.S. Climate Change Science Program, Washington, D.C., 202 p.

National Research Council, 2001, Future Roles and Opportunities for the U.S. Geological Survey, National Academy Press, Washington, D.C., 179 p.

APPENDIX 1: Earth Surface Dynamics Program 5 year Plan Writing Team and Reviewers

Chair: Nicholas Lancaster (Program Coordinator)

Bob Thompson (CESPT, Denver)
Jennifer Harden (VHT, Menl0 Park)
Gary Clow,(CESPT, Denver)
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Tom Loveland, Dave Kirtland (Geography)
Jack Waide, Martha Garcia (BRD)

External reviewers
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Chris Miller (NOAA)