The National Map

Geographic Analysis and Monitoring Program

5- Year Program Plan

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I. Executive Summary

The Geographic Analysis and Monitoring (GAM) Program assesses the Earth's land surface at a range of spatial and temporal scales to understand the rates, causes, and consequences of land surface change caused by natural and human-induced processes, and their interactions that affect the landscape and environment over time. The program conducts long-term studies of the land use and disturbance histories of the United States and selected overseas areas, determines the reasons for change, conducts research leading to improved understanding and knowledge about geographic processes, and produces reports on the status and trends in our Nation's land surface.

The GAM Program is part of the U.S. Geological Survey's (USGS) Mapping, Remote Sensing, and Geographic Investigations (MRSGI) Activity and contributes to *The National Map*, a dynamic, evolving source of national geographic information. *The National Map* is comprised of a seamless, continually maintained, nationally consistent, vertically and horizontally integrated geospatial database, a satellite land surface monitoring system, and geographic assessments of the status and trends of the Earth's land surface. The GAM Program adds scientific value to *The National Map* through investigations of natural and human-induced changes on the landscape that provide knowledge and understanding to the spatial content of *The National Map*.

The GAM Program's mission is to bring focus to the Nation's urgent environmental, natural resource, and economic issues through scientific assessments that provide a national and global perspective on land surface change. The GAM Program will work to institutionalize the development of a report series on the status and trends of the Nation's land resources. Research activities will focus on clarifying the impact of land surface change on the activities and well-being of the American people by providing unbiased scientific information on the rates and trends of contemporary land surface change needed for effective land management. The GAM Program will identify the relevant indicators of land surface change, develop monitoring protocols and methodologies, and model the associations between habitat patterns and biological processes. The program will also quantify rates of land surface change, identify key driving forces, and forecast future trends. All research studies will be conducted within a geographic context and at a range of spatial and temporal scales.

The GAM Program addresses four fundamental scientific issues concerning changes at the Earth's land surface. Specifically, GAM strives to achieve the following:

- Understand what changes are occurring on the land surface and why,
- Understand the impacts of these land surface changes on ecosystem health, climate variability, biogeochemical cycles, hydrology, and human health,
- Understand how these impacts may in turn affect the land surface through feedback mechanisms, and
- Understand what the best methods are to incorporate GAM science findings in the

decision-making process.

To investigate these scientific issues, the GAM Program is pursuing the following 5-year goals:

- Analyze, understand, model, and predict the consequences of historical and projected land surface changes on ecosystem health, taking into account natural and human-induced stimuli at regional, continental, and global scales.

- Determine and quantify the impacts of land use and land cover change on regional climate variability and biogeochemistry, including potential feedback processes.

- Understand the influences and interactions between infectious diseases and the environment.

- Analyze and interpret the record of land use dynamics that includes land use and land cover change to enhance understanding of the physical and social drivers of land surface change.

- Conduct long-term monitoring of the state and trends of the Earth's land surface as critical input for regional and national policy decisionmaking.

- Develop advanced techniques to monitor land surface change and ecosystem structure and function, in a spatially explicit fashion.

- Develop methods to communicate research results and assist decisionmakers with ecosystem strategies and sustainability.

Studies conducted by the GAM Program focus on providing comprehensive information needed to understand the environmental, resource, and economic consequences of land surface change. Innovative applications, such as natural resource utilization, ecosystem health, climatic and hydrologic variability, biogeochemical cycles, hazards response (including drought monitoring and flood inundation mapping), human health and infectious disease control, effects of wildland fire, and environmental modeling, are conducted to provide a basis for resource managers and the public to understand the dynamic nature of our landscape and to anticipate the opportunities and consequences of natural processes and human actions.

The primary customers for products from the GAM Program are the scientific community, State and Federal agencies, and public organizations that make land management decisions or influence and shape policy. The GAM Program works closely with stakeholders within the Department of the Interior (DOI) Bureaus having land surface management roles, such as the Bureau of Land Management, the National Parks Service, and the Bureau of Reclamation. The program also supports U.S. international agencies and international donors as expertise from the USGS is called upon in international applications. In the past, customers have included national agencies with regulatory or land management roles, such as the U.S. Environmental Protection Agency, the U.S. Forest Service, the National Oceanic and Atmospheric Administration

(NOAA), the National Weather Service, and the U.S. Agency for International Development (USAID).

The key impetus for this program is stated in the USGS Strategic Plan. 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 the quality of life. By conducting assessments to understand the rates, causes, and consequences of land surface change, the program will provide an understanding critical to geographic investigations within the United States and in support of foreign policy initiatives, especially in developing countries.

The GAM Program can leverage many opportunities for collaboration with other USGS science programs. Engaging these programs will be a challenge. The GAM Program will need to identify appropriate research partners, establish goals for mutual research, and measure performance in reaching those goals. Potential linkages will be explored with the Status and Trends, Ecosystems, Earth Surface Dynamics, National Water Quality Assessment, Land Remote Sensing, and Cooperative Topographic Mapping Programs.

II. Introduction

As human population grows, we make use of our land in increasingly complex and potentially conflicting ways and as the value of our land becomes more evident, it has become more important than ever that we map, monitor, and understand the land surface and predict the outcomes of things that may cause change. Likewise, as mapping and analytical technologies have become more affordable and, therefore, nearly ubiquitous, redundancy and fragmentation of data collection and analysis have become the norm. Still, the problems being addressed by these geographic activities often transcend jurisdictional boundaries.

The strategic vision of the Mapping, Remote Sensing and Geographic Investigations (MRSGI) activity of the USGS is to take the next logical step, The National Map. It will provide flexible current and historical digital geographic information to meet national needs. Operated as a partnership, it will be a dynamic source of national geographic information comprised of seamless, continually maintained, nationally consistent, vertically and horizontally integrated geospatial databases; a satellite land surface monitoring system; and geographic assessments of the status and trends of the Earth's land surface.

The National Map will manifest itself in several ways. Firstly, The National Map will be visible as a publicly accessible Internet portal to a set of relevant, seamless, nationally consistent, integrated, and documented geographic information that will provide a trusted source of basic geographic information needed by government at all levels. Secondly, The National Map will be visible as regularly published scientific studies and analysis of these and other geographic information, which will provide a deeper understanding of earth surface changes and trends. Thirdly, The National Map will be visible as a service that links this information and other geographic information to validated services and applications, which will guide the proper use of the information in government applications. And finally, The National Map will be visible as a network of partnerships at all levels of government to share selected geographic information and a network of public-private partnerships for geographic information collection, dissemination, and technology development.

All three MRSGI programs, the Cooperative Topographic Mapping (CTM), Land Remote Sensing (LRS), and Geographic Analysis and Monitoring (GAM), will contribute to *The National Map* in the following ways:

- The CTM Program will assemble, maintain, archive, and provide access to base layers of geospatial data (orthoimagery, elevation, hydrography, transportation, structures, boundaries, land cover, and geographic names). Applied geographic and cartographic research and development will be a support component of this program.

- The LRS Program will operate and maintain on-orbit government satellites; collect and archive national and global coverages of Landsat and other land remotely sensed data; provide remotely sensed geospatial data for *The National Map*; respond to the Nation's needs for current geographic information in support of homeland security; and advance our understanding and use of the science of remote sensing through research.

- The GAM Program will provide reports on the status and trends of the Nation's land resources, produce a land use and land cover database for the periodically updated Geographic Face of the Nation, conduct research leading to improved understanding and knowledge about geographic processes, and develop new applications capabilities with which the data from the CTM and LRS Programs can be used.

The GAM Program adds scientific value to *The National Map* through investigations of natural and human-induced changes on the landscape that provide knowledge and understanding to the spatial content of *The National Map*. GAM scientific investigations help identify new or refine existing data requirements for *The National Map,* thus enabling users to more effectively use information for research, analysis, modeling, and prediction of land surface change.

Partnerships are a key component and foundation of *The National Map*. The strategic goals of *The National Map* cannot be reached without the active participation of other entities and organizations, including internal and external cooperators, business partners, volunteers, and government and private organizations. The GAM Program collaborates with and provides information to a broad assortment of Federal, State, and private sector interests that look to the USGS for a nationally consistent description of current land surface and land use conditions for the Nation. These partners and customers seek to enhance their scientific understanding of land surface change to better manage public lands, develop effective policy, manage resources, and convey to the public the effects of their decisions. The GAM strategy will be to increase the participation of partners through collaboration involving a variety of resources. Combining partner resources with appropriated funding will enable GAM to reach greater program strength while contributing to land use trends that are of interest to partners and customers. The strategy of the GAM Program over the next 5 years will include these actions:

- increase the resource-sharing partnerships in which its scientists participate
- increase the number of agreements that bring partner resources to the GAM Program
- increase cooperative relationships with academic institutions

- build strong national advocacies

The National Map is built upon and uses existing congressional legislation to help frame its goals and objectives. In this context, GAM refers to the following bills to frame its research, goals, and objectives:

- The Organic Act of 1879 which established the USGS to "classify the public lands and examine the geological structure, mineral resources, and products within the national domain"
- The National Climate Program Act of 1978 which directed research "to assist the Nation and the world in understanding and responding to natural and human-induced climate processes and their known and potential effects"
- The Global Change Research Act of 1990 which required research aimed at "understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment"

Program History

The GAM Program was established during the restructuring of the National Mapping Program in 2002. This change created three USGS programs (CTM, LRS, and GAM) to better clarify and communicate the Geography Discipline activities to Congress, customers, stakeholders, and citizens. The three programs together underpin and implement *The National Map*. The new programs also enable stronger collaboration and integration with other Bureau science programs.

Although the GAM Program is new, current activities build upon and continue functions and responsibilities associated with the former USGS Geographic Research and Applications (GRA) subactivity and incorporate functional responsibilities of the former Earth Science Information Management and Delivery (ESIMD) subactivity. ESIMD's functions and responsibilities that are now part of GAM include data and product archiving, data maintenance, and data dissemination activities. The program continues a rich legacy of geographic research developed through GRA's innovative, integrated, and interdisciplinary scientific investigations attentive to land surface description and analysis. The legacy of GRA's research goals that are relevant to GAM include the following:

- to monitor, record, and understand land surface change and human interactions with the land's surface,
- to advance the state of knowledge in geography,
- to use geography as a framework for integrating results from other science disciplines' research, and
- to maintain and advance national capabilities in geographic tools, such as remote sensing, image processing, and geographic information systems (GIS).

Current Accomplishments

The GAM Program builds upon a tradition of land cover mapping activities within the USGS.

These roots extend to the USGS Geography Program of the 1970s. At that time, the program embarked on a plan to map, describe, and monitor the changing national landscape – objectives similar to those of GAM. The cornerstone and legacy of the Geography Program is a USGS Professional Paper on "A Land Use and Land Cover Classification System for Use with Remote Sensor Data" in which the Chief Geographer, James Anderson, and colleagues prepared a classification system and intellectual framework for using remotely sensed data to map and monitor land use and land cover change. The system has become a *de facto* international standard and continues to be widely used.

During the late-1970s, the USGS used the Anderson system with remotely sensed data to map land use and land cover (1:250,000-scale) across the conterminous United States. The resulting high-resolution database was in most ways "ahead of its time," as it was designed from the outset to be a digital layer used in the then-emerging GIS technology. The resulting national land cover database, along with associated maps showing political units (counties and States), hydrologic units (drainage areas), census county subdivisions (including census tracts), and areas of Federal land ownership, became the USGS Geographic Information Retrieval and Analysis System – one of the Nation's first analytical GISs.

Other geographic research landmarks of the USGS include the following:

- The National Atlas published in 1970, depicting the physical, social, economic, and cultural patterns of the United States.

- The Central Atlantic Regional Ecological Test Site and Arizona Regional Ecological Test Site studies, completed in the mid-1970s, served as the first demonstrations of large-area ecological assessments using Landsat and other remotely sensed data.

- In the 1980s, innovative land management applications of GISs and remote sensing were developed in partnership with DOI agencies to facilitate the adoption of new technologies.

- Mapping of vegetation and land cover for more than 75 percent of Alaska in cooperation with DOI and other Federal and State agencies using Landsat data in the 1980s. Vegetation inventory data were required by the Alaska National Interest Lands Conservation Act.

- In 1993-94, the USGS led in the formation of the interagency and interdisciplinary Scientific Assessment and Strategy Team which conducted an exhaustive and comprehensive analysis of the causes, consequences, and mitigation of the 1993 Great Flood of the Upper Mississippi River Basin (http://edc.usgs.gov/sast/).

- The USGS completed innovative research in the mid-1990s on new strategies for characterizing the national to global land cover. Included in the research were a series of collaborative experiments that collectively demonstrated the role of flexible land cover characterization approaches for improving large-area environmental simulation modeling.

- As part of the U.S. Global Change Research Program, the first high-resolution (1-km) global land cover (http://landcover.usgs.gov/globallandcover.html) and global elevation databases (http://edcwww.cr.usgs.gov/products/elevation/gtopo30.html) were completed in the late-1990s. Global change research projects also investigated the effects of land use change on the carbon cycle and regional climate variability.

- In the late 1990s, USGS developed a 30-meter resolution National Land Cover Dataset (NLCD) for the conterminous United States derived from Landsat satellite data. The NLCD dataset is based on a 21-category land cover classification scheme that is applied consistently over the conterminous United States and includes ancillary data sources, such as topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data (http://edcwww.cr.usgs.gov/products/landcover/nlcd.html).

- In the late 1990s, USGS developed a seamless 30-m digital national elevation model and topographic derivatives datasets for the conterminous United States (http://edcwww.cr.usgs.gov/products/elevation/ned.html).

- The role of an integrated GIS and remote sensing-based analysis for the operational assessment of food security and other natural and human hazards was demonstrated throughout Africa and other parts of the world throughout the 1990s (http://edcsnw3.cr.usgs.gov/ip/index.html).

- In the late-1990s, the Urban Dynamics Program was established, which provided assessments of urban land use change for dozens of U.S. metropolitan areas and a capability for modeling future changes (http://landcover.usgs.gov/urban/intro.html).

In many ways, the accomplishments of the past, highlight the challenges of the future. At the same time, those accomplishments provide the foundation for more innovation in geographic research of land use dynamics and associated environmental assessments.

Challenges from Land Use Dynamics

The Earth's surface is changing rapidly, at scales from local to global, altering how ecosystems function and disrupting ecosystem services in ways that are not well understood. For example, changes in land use and land cover have significant influence on economic development and environmental quality at multiple scales. Human-induced and natural land surface transformations plus regional climate variability affect ecosystem processes, habitat fragmentation, surface and ground water quality and availability, biogeochemical cycles, vector-borne disease propagation, invasive species introduction, natural resource accessibility, and vulnerability to natural hazards. These changes are modifying the Earth's landscape with significant consequences for ecosystem health and sustainability.

Ecosystem change has occurred throughout the Earth's history. Change has usually resulted from natural succession, with occasional disturbances caused by natural events, such as flooding, windstorms, climate variability, landslides, disease and insect infestation, and wildland fires.

Today, there is increased recognition that land surface change is a major driver of a wide spectrum of environmental consequences through its interaction with ecosystem processes, biogeochemical cycles, biodiversity, and climate system (Nunes and Augé, 1999). Evolving local land use patterns, formed by various biophysical and human processes, result in land surface changes that affect ecosystem health through unwanted changes in biodiversity, productivity, water and energy budgets, and trace-gas emissions. Human vulnerability can increase through settlement in hazard-prone areas. Cumulatively, these changes on local ecosystems can alter the global climate and biosphere (Riebsame and others, 1994), with potentially serious adverse consequences for quality of life.

Unprecedented rates of land surface change and the corresponding impacts on biological resources are creating growing public concern. For example, the expansion of agricultural land and its use in manners not sustainable are now widely recognized as having caused one of the most significant human alterations to the global environment. This impact has always been seen regionally, but only recently has its enduring potential to affect the global climate system become understood. The total area of cultivated land worldwide increased 466 percent from 1700 to 1980 (Matson et al., 1997). At the global scale, land used for cropping encompasses nearly 28 million km^2, or approximately 19 percent of the Earth's land surface (Loveland, 2000). Only forests cover a larger area of the global land surface (40 million km^2 or 27 percent) (Meyer and Turner, 1992). Although the transformation of natural vegetation to croplands has slowed in the last three decades, agricultural practices have increased in intensity. There is clear evidence that agricultural intensification can have negative local consequences, such as increased soil erosion, lower soil fertility, and reduced biodiversity; negative regional consequences, such as pollution of ground water and eutrophication of rivers and lakes, and negative global consequences, such as atmospheric pollution and climate change (Matson et al., 1997). Yet, in a system of expanding human populations, as work in developing countries indicates, agricultural intensification is the only real alternative, and only this achievement will reduce the encroachment on forested areas documented above. USGS research can help understand these ecosystem processes adequately to ensure that intensification, wherever undertaken, is sustainable for the environment and society.

Almost half of the conterminous 48 States were covered with forests before European settlement. Forest area began a significant decline with the onset of European settlement and continued until the early 20th century. Today approximately 29 percent (2.3 million km^2) of the conterminous United States is forested. Fifty-three percent of American wetlands were lost between the 1780s and the 1980s, principally because of drainage for agriculture. Most of the conversion took place in the 20th century. Between the 1950s and 1970s alone, 445,000 km^2 of wetlands were lost. Land cover work in sub-Saharan Africa has shown that woodlands over broad areas have nearly vanished and soils are now nutrient depleted and devoid of the soil organic carbon stocks needed to store plant nutrients.

The composition of U.S. land cover stabilized somewhat in the latter half of the 20th century, though some areas are clearly undergoing significant land use and land cover transformations at the present time (Waisanen and Bliss, in press). In a study on the impacts of land use change on natural vegetation, it was determined that 23 of the 106 natural vegetation types occurring in the United States at the time of European settlement have been reduced by more than 50 percent through human-induced land use changes (Klopatek et al., 1979). In contrast, only 26 natural vegetation types have had less than 5 percent of their potential area converted to urban or agricultural land uses. Today, we are still experiencing significant changes in land use and land cover. The Southeastern U.S. region has experienced rates of change exceeding 5 percent every 6-8 years for the past 20 years, with some ecoregions experiencing even higher rates owing to the urbanization and the transformation to plantation forestry (Loveland and others, in press).

Population growth and migration patterns are recognized drivers of human-induced land surface change. Since the 1960s, the population of the United States has increased from 179 to 281 million. Although birth rates are declining or holding steady in many regions, the U.S. Census Bureau projects a 50-percent increase in population to 383 million by the year 2050. These projections suggest significant changes in land use that will likely have major consequences on ecosystem health and sustainability. Increased national affluence, combined with ease of movement, is generating a population shift that may have an impact on some of our most critical and currently undisturbed ecosystems as migration increases from urban to rural communities, often adjacent to national parks and other scenic areas (Diamond and Noonan, 1996).

Calls for Research on Land Use Dynamics

There is a clear scientific call for research on land surface change. For example, the U.S. Global Change Research Program (USGCRP) has designated land use and land cover dynamics, terrestrial and aquatic ecosystem functioning, climate variability, the global carbon cycle, and the global water cycle as focus areas for the new 10-year plan on USGCRP-sponsored global environmental change research. In addition, the International Geosphere-Biosphere Programme of the International Congress of Scientific Unions has established core research programs in Global Change and Terrestrial Ecology (Steffen et al., 1992) and Land Use and Cover Change (Turner et al., 1995).

Perhaps the clearest call for research requiring geographic analysis and monitoring resulted from the National Research Council (NRC) response to a National Science Foundation request to identify the "Grand Challenges in Environmental Sciences" (NRC, 2001b). An interdisciplinary committee was asked to determine the most important research challenges in environmental sciences. The NRC (2001b) report examined significant research challenges for the next 20- to 30-year period and identified eight grand challenges. Among these, Grand Challenge 7 concerning Land Use Dynamics is especially relevant to the core mission of the GAM Program and is cited from the NRC (2001b) as follows:

- Grand Challenge 7: **Land Use Dynamics**: The challenge is to develop a comprehensive understanding of changes in land uses and land covers that are critical to biogeochemical cycling, ecosystem functioning and services, and human welfare.

Several other Grand Challenges recommended by the NRC (2001b) are also relevant to GAM and include the following:

- Grand Challenge 1: **Biogeochemical Cycles**: The challenge is to understand how the Earth's major biogeochemical cycles are being modified by human activities in order to develop the capacity to predict the impact of these changes at local, regional, and global scales,

- Grand Challenge 2: **Biological Diversity and Ecosystem Functioning**: The challenge is to understand the regulation and functional consequences of changes in biological diversity and to develop strategies for sustaining biological diversity and interdependent ecosystem functions.

- Grand Challenge 3: **Climate Variability**: The challenge is to increase our ability to predict climate variability, from extreme events to decadal time scales; to understand how this variability may change in the future; and to assess its impact on natural and human systems.

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- Grand Challenge 4: **Hydrologic Forecasting**: The challenge is to predict changes in freshwater resources and the environment caused by floods, droughts, sedimentation, and contamination in a context of growing demand on water resources.

- Grand challenge 5: **Infectious Disease and the Environment**: The challenge is to understand the ecological and evolutionary aspects of infectious diseases; to develop an understanding of the interactions among pathogens, hosts/receptors, and the environment; and thus to make it possible to prevent changes in the infectivity and virulence of organisms that threaten plant, animal, and human health at the population level.

Research Priorities

The USGS must undertake an aggressive science program that enables citizens, resource managers, and decisionmakers to understand the opportunities for improving and sustaining our Nation's land resources. The GAM Program provides a powerful analytical framework for a broad area of research addressing the complex interactions among human activities, natural ecosystem processes, and the Earth's climate system. Geographic analysis is an important tool to help understand these complex processes. The GAM Program plans to focus on investigating the consequences of land surface change in terms of ecosystem health, climate variability, biogeochemical cycles, hydrology, human health, sustainability of resources, and vulnerability of ecosystems and human populations to environmental hazards.

The GAM Program seeks to provide leadership in understanding the consequences of land surface change and in developing sound science that will support assessments of ecosystem condition and performance. An integrated research approach with a focus on ecosystem health, integrity, sustainability, and land surface monitoring is necessary to accomplish these goals.

Research needs to be initiated that examines how ecosystems react to change, from both natural and human-induced stresses. An understanding of ecosystem response to changes in the factors that drive ecosystem behavior is important to prescribe ecosystem restoration and management strategies that would enhance the sustainability of Earth's ecological systems.

New tools, methodologies, and interdisciplinary approaches must be developed for strengthening the capacity to assess the sustainability of ecosystems to provide goods and services and for understanding the potential consequences of future changes in ecosystems.

An improved understanding of the causes and mechanisms that underlie current and past land surface changes is required to develop an ability to predict future changes. Improved predictive models, including decision support systems for land use planning and improved assessment of the likely outcomes of alternative land use scenarios, must be developed to assist managers in their activities.

An improved understanding and more information about the consequences of these land surface changes is needed to aid decisionmakers dealing with land use planning, land management, natural hazards mitigation, and natural resource conservation. Understanding land surface change and the interactions between natural processes and human-induced change is essential for making informed decisions that best accommodate both land development and conservation goals. Responsible land management decisions depend on understanding, quantifying, and predicting how ecosystem functions will change as a consequence of new patterns of land use. The need for better information about causes and implications is especially evident for changes induced by fire, agricultural production, urbanization, logging, climate variability, and other factors operating at broad regional scales.

III. Program Mission and Long-Term Goals

Program Mission

The GAM Program assesses the Earth's land surface at a range of spatial and temporal scales to understand the rates, causes, and consequences of land surface change caused by natural and human-induced processes and their interactions that affect the landscape and environment over time. The program conducts long-term studies of the land use and disturbance histories of the United States and selected overseas areas, determines the reasons for change, and produces reports on the status and trends in our Nation's land surface. Geographic analysis determines the consequences of land surface change in terms of potential impacts and two-way feedbacks concerning ecosystem health, climate variability, biogeochemical cycles, hydrology, and human health. The program addresses questions concerning the sustainability of resources, vulnerability of ecosystems and human populations, and evaluation of development options in terms of their potential influences on land surface status and trends.

The GAM Program's mission is to bring focus to the Nation's urgent environmental, natural resource, and economic issues through scientific assessments that provide a national and global perspective on land surface change. The GAM Program will work to institutionalize the development of a report series on the status and trends of the Nation's land resources. Research activities will focus on clarifying the impact of land surface change on the activities and well-being of the American people by providing unbiased scientific information on the rates and trends of contemporary land surface change needed for effective land management. The GAM Program will identify the relevant indicators of land surface change, develop monitoring protocols and methodologies, and model the associations between habitat patterns and biological processes. The program will also quantify rates of land surface change, identify key driving forces, and forecast future trends. Many innovative applications will be developed that associate human and natural processes with endangered species, ecosystem health, land use patterns, vulnerability to natural hazards, climate variability, changes in environmental chemistry, and the effects of wildland fire.

The GAM Program addresses four fundamental scientific issues concerning changes at the Earth's land surface. Specifically, GAM strives to achieve the following:

- Understand what changes are occurring on the land surface and why,

- Understand the impacts of these land surface changes on ecosystem health, climate variability, biogeochemical cycles, hydrology, and human health, and

- Understand how these impacts may in turn affect the land surface by feedback mechanisms.

- Understand what the best methods are to incorporate GAM science findings in the decision-making process.

The U.S. Government extends economic, development, and humanitarian assistance to friends and allies in the developing world. Many of these countries are faced with threats because of resource depletion, land degradation, floods, droughts, and other natural hazards. U.S. assistance is often designed to help in these areas, but design and implementation can be seriously hampered by out-of-date and spatially sparse environmental information. The GAM Program seeks to provide technical assistance to partners to overcome these difficulties. Remote sensing and spatial analysis of processes over wide areas compensate for the severe lack of basic environmental information. In this way, lessons learned through case studies and sampling at the local level can be generalized to guide policy formulation and decisionmaking that have direct impacts on the interplay between human enterprise, ecosystem processes, and the Earth's climate system.

Bureau and DOI Context

The GAM Program mission closely aligns with the mission of the USGS. Within this context, the GAM mission directly supports the Bureau mission to serve the Nation by providing reliable scientific information to do the following:

- describe and understand the Earth,
- minimize loss of life and property from natural disasters (especially those caused by human-induced changes to the land surface),
- manage water, biological, energy, and mineral resources, and
- enhance and protect our quality of life.

GAM research uses geography as a framework for integrating results from other science disciplines. GAM will contribute to the integration of the Bureau's biological, physical, and social sciences to provide a more thorough understanding of the consequences of change that will be useful for land management decisions.

The GAM Program mission closely aligns with the DOI mission as well. The GAM Program supports USGS efforts to provide information and technologies that are critical to DOI's mission on stewardship of the Nation's land resources. The GAM Program helps the USGS to support the DOI's strategic goals, most directly Goal 4, "Provide Science for a Changing World."

The DOI has defined the following outcomes for its Goal 4:

- Resource managers make decisions on the basis of accurate, reliable, and impartial scientific information.
- The loss of life and property from natural disasters is minimized through access to and availability of timely scientific information.
- Federal, State, and local governments and the private sector have access to shared national databases of natural resources information.
- The public has easy access to earth science information.

Legislative Context

GAM research is broadly covered by the Organic Act of 1879 (43 U.S.C. 31 et seq.) establishing the USGS to "classify the public lands and examine the geological structure, mineral resources, and products within the national domain". Other authorizations exist that establish programs whose activities relate indirectly to the GAM mission including those shown below:

The National Climate Program Act of 1978 (15 U.S.C. 2901, 2908) established a national climate program to assist the Nation and the world in understanding and responding to natural and human-induced climate processes and their known and potential effects. The DOI has a mandated role in this Program.

The Global Change Research Act of 1990 (15 U.S.C. 2921-2953) (Public Law 101-606) established the U.S. 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), promoting discussions toward international protocols in global change research.

The Land Remote Sensing Policy Act of 1992 (15 U.S.C. 5631-5658) enabled the United States to maintain its leadership in land remote sensing by providing data continuity for the Landsat Program. The Act assigns responsibility for the "National Satellite Land Remote Sensing Data Archive" to the DOI. The Act also authorized and encourages the DOI and other Federal agencies to carry out research and development programs in applications of these data and make Landsat data available to the public.

The Federal Water Pollution Control Act Amendment of 1972 (33 U.S.C. 1251 et seq.) and its successors, the Clean Water Act of 1977 and the Water Quality Act of 1987, authorized extensive water quality planning, studies, and monitoring primarily under the direction of the

Environmental Protection Agency (EPA). The USGS is called upon to participate in many of these activities, partly by the EPA and partly by State agencies in the Federal-State Cooperative Program. The act of 1987 includes new water quality work concerning Chesapeake Bay, the Great Lakes, Estuary, and Clean Lakes Programs, and studies of water pollution problems in aquifers.

The Estuaries and Clean Waters Act of 2000 (Public Law 106-457) amended the Federal Water Pollution and Control Act (commonly know as the Clean Water Act) to include authorization for many activities, including Chesapeake Bay Restoration and the National Estuary Program. The USGS is a key Federal partner in the Chesapeake Bay Program and the National Estuary Program.

Strategic Plan Context

The Bureau Strategic Plan reflects a commitment to serve as the Nation's principal natural sciences and information agency by conducting research, monitoring, and assessments that contribute to our understanding of the natural world – our land, water, and biological resources. This commitment aligns closely with GAM's Program mission to provide data and information on the Nation's land surface.

The USGS Strategic Plan identifies two broad mission goals – Hazards, and Environment and Natural Resources. These mission goals were derived from organizing USGS activities in a way that would be useful for natural science customers and serve as a framework for marshalling the Bureau's expertise in geology, biology, hydrology, and geography to meet societal issues.

The GAM Program plays a major role in both goals. GAM science contributes to a better understanding of the effects of land surface change on flood and fire hazards. For example, GAM fire science research is improving our spatial knowledge of the current and historical dynamics of fire and its effects. It is assessing fire disturbance regimes and the accumulation of fire fuels to understand the impact of fire on ecosystems.

The GAM Program contributes to the Environment and Natural Resources Goal by improving the development and use of national and temporal data, maps, and information, and by providing strategies and options for decisionmakers to better understand and mitigate the effects of land surface change on the Nation's land, water, and biologic resources.

The Bureau Strategic Plan also stresses customer service, underscoring the application of science to customer, partner, and other stakeholder needs. Within this context, GAM is seeking to enhance and build stronger alliances with current partners so they may become advocates representing program stakeholders and national organizations. Through focus group meetings and listening sessions, GAM is encouraging its customers and stakeholders to communicate and describe more effectively the utility and value of documenting, measuring, and accessing land surface change.

Long-Term Goals

The long-term goals of the GAM Program are as follows:

- Provide a nationally consistent description of historical land use conditions for the Nation and define long-term trends in land surface conditions.

- Identify, describe, and explain major factors that affect the rates and trends of land surface change.

- Advance the understanding of the consequences of land surface change at various scales for abiotic (physical), biotic (biological), and anthropogenic (human) systems.

- Ensure that information is made available to land managers, policymakers, and the public to provide an improved scientific basis for evaluating the effectiveness of land management programs and for predicting the likely effects of contemplated changes in land management practices.

IV. Program 5-Year Goals

Goals and Objectives

The program will work toward seven research goals over the next 5 years. Annual guidance will define the detailed research priorities that guide the development of research proposals that address the goals and objectives of the program. Listed below are the GAM Program's 5-Year Goals:

Goal 1: Analyze, understand, model, and predict the consequences of historical and projected land surface changes on ecosystem health, taking into account natural and human-induced stimuli at regional, continental, and global scales.

Justification: Natural ecosystems are being altered by the impacts of land surface change. Cities and suburbs are expanding, natural resources are being extracted, and land is being farmed, all of which are altering important ecological patterns and processes and threatening the ecological sustainability of natural systems. Key ecological issues facing land managers and planners include fragmentation of continuous habitat, accumulation of toxins and nutrients, alterations in the hydrologic cycle, climate variability, degradation of soil resources (carbon, nutrients, and structure), loss of biodiversity, expansion of invasive species, and altered fire regimes. An understanding of the ecology of critical environments is essential. Resource managers require assistance from the scientific research community to determine the course and effectiveness of projects and programs to achieve ecosystem integrity.

Intensified land use, if not managed appropriately, can diminish the capacity of ecosystems to provide important functions critical to maintaining either the environment itself or the quality of life people have come to expect. Scientific investigations of the impacts of wildland fire, resource extraction, urbanization, climate variability, and other changes need to be conducted to develop methods for managing land in response to those impacts. Several types of change may combine to stress an ecosystem, such as the collapse of salmon populations following modifications to spawning streams (water management) and their host watersheds (land use). Regulations and decisions typically have been based on site-specific analysis. New ecosystem understanding now requires that we consider larger areas and longer time spans, specifically the ability to scale site-specific information (for example, a soil chemical analysis, sparse weather station information, or CO_2 flux observations) to regional and global applications. It is the nature of large-area and long-time-span systems to involve all elements of the landscape: physical, biological, and cultural. Thus, interdisciplinary science is required for place-based ecosystem studies.

This ecosystem health research can capitalize on USGS international project work in sub-Saharan Africa. For example, recent studies suggested that management of agricultural intensification in a sustainable manner yields more harvestable products for human use and decreases the impacts on biodiversity and the environment. Another USGS study in sub-Saharan Africa provides insights into data integration and analysis for near real-time monitoring, spatial modeling, and scaling used by the famine early warning system (FEWS) in Africa for drought and flood hazards. For example, hydrologic forecasting to identify drought and flood hazards has long been limited by sparse hydrometeorological surface observations and little understanding of the interactions between the land surface and atmosphere. Assessment of long-term and interannual impacts on ecosystems and related human economic activity can be improved through the application of Earth-observing remote sensing systems, techniques of GIS, and newly available and globally complete datasets describing topography, land cover, and soils. In particular, the impacts of changing land cover (either for better or for worse) on the timing and magnitude of flooding events can now be more readily addressed through remote sensing and GIS support of physically based, distributed parameter hydrologic modeling. Similar effects of changing climate patterns can also be ascertained more explicitly with available satellite imagery, geographic data, and software for spatial analysis.

The USGS 30-m seamless digital elevation model (DEM) data, including topographic derivatives for the conterminous United States can be used to understand the hydrologic component of ecosystem structure and function, and to geographically analyze land surface change effects on ecosystem health. This approach involves analyzing landscape-connectedness within a hydrologic context. With newly developed datasets and tools, it is now possible to use geographic analysis to answer questions about the surface, such as, “What are the land cover characteristics of the area upstream from this point?” and “Are these two areas of change connected or disconnected when analyzed in the context of stream flow?” The connectedness of the landscape will be analyzed within the GAM Program for national-scale characteristics, such as those of large rivers and their watersheds, and regional characteristics, such as those of the spatial components of ecosystems and local behavior in small areas of change.

The USGS conducts many investigations of specific ecosystems, often investigating a particular question or need, with the expectation that the completed work will be transferable to other sites in the region or the Nation. Ecosystem and land surface change studies cannot be handled at a single scale of observation. An understanding of how processes operate at various spatial scales and how they can be linked across scales becomes a primary goal when investigating these complex phenomena (Marceau, 1999). Research is done on strategies and procedures for ensuring that the results of these site-based investigations can be used to help answer questions of national importance. The USGS needs to implement the National Research Council's (2001a) recommendation that it place more emphasis on multidisciplinary, integrative projects that address environmental issues on a national scale, but the Bureau will still be involved with various site-specific investigations and assessments. The USGS should be committed to providing national leadership in integrating and extending the results of ecosystem research at all levels.

GAM research will seek answers to the following questions: What are the regional environmental consequences of land surface change at various scales on ecosystem health and for abiotic and biotic systems? What are the effects of land surface and land use change on habitat and biodiversity? What is the state of the ecological integrity and ecosystem health for major metropolitan areas? How can we put site-based studies of ecosystem processes into a spatial context so that we can extrapolate the results of those studies over larger geographic areas (drainage basins, landscapes, ecoregions)?

Objectives: Develop a series of hypotheses that link site-specific landscape processes and interecosystem processes into a larger framework. Establish a national framework suitable for coordinating and integrating site-based investigations of ecosystems so that results and conclusions can be evaluated and extended to other systems at the same or greater spatial scales. To enhance sustainability, examine the interconnectedness among natural resources and processes as they affect and are affected by human systems. Assimilate data from gages, satellites, weather forecast models, and digital maps of land cover, soils, and topography in a common modeling framework using GIS. Apply advanced models of climate, water, and carbon cycle processes and decision support tools to simulate linkages among terrestrial and aquatic ecosystems across spatial and temporal scales.

Goal 2: Determine and quantify the impacts of land use and land cover change on regional climate variability and biogeochemistry, including potential feedback processes.

Justification: Complex interrelationships, including potential feedbacks, exist among land cover and land use changes, regional climate variability, and biogeochemical cycles. Reducing uncertainty and understanding these interrelationships is difficult, especially if variations and dependencies are influenced by both natural and anthropogenic forcing factors. Climate variability can affect the land surface (for example, vegetation and ecosystems) and biogeochemical cycles. Conversely, land use change can affect the carbon cycle, and there is growing evidence that land use changes can also affect regional climate and weather variability. Such human-induced changes can contribute to either positive or negative feedbacks on land surface processes and the land surface. To illustrate, land use change may increase land surface temperatures and reduce seasonal rainfall amounts, which may then adversely affect ecosystem processes and agricultural activities. Understanding such complex systems and feedbacks cannot be accomplished without the use of integrative system models (NRC, 2001a). Furthermore, NRC (2001a) recommended that the “USGS emphasize system modeling as a powerful tool for integrative science in the 21st Century.” Such a coupled-systems modeling approach could involve the linking of land surface, ecosystem, and biogeochemical models with a regional atmospheric model to help understand these complex processes and to quantify the consequences of land surface change. Reconstructed historical land use datasets are a key input for hypothesis testing in these types of modeling experiments. Historical observational records and paleo-datasets from geologic studies are needed to help evaluate the model results.

For example, a key research challenge in the climate change science community is to develop a greater understanding of the relationships among land cover, land use, climate, and weather. Research is needed to understand how changes in land cover and land use patterns may affect local and regional climate, including land processes such as the surface energy balance, surface temperatures, and precipitation patterns. Furthermore, investigations are needed to understand how altered temperature and precipitation patterns affect terrestrial ecosystems.

As a second example, many scientists have determined that there is a connection between the buildup of greenhouse gases in the atmosphere and global warming. Global warming is anticipated to have far-reaching effects on many aspects of human activity, including the possibilities of increased frequency of severe storms, droughts, and floods, stresses to natural ecosystems and to agricultural production, and direct and indirect impacts on human health. Two of the primary greenhouse gases, carbon dioxide (CO_2) and methane (CH_4), are part of the carbon cycle. Before the human influences of fossil-fuel burning and land conversion to agriculture, the processes that store carbon on the landscape (sequestration of CO_2 by photosynthesis) were most likely in rough balance with the processes that release carbon to the atmosphere (respiration by plants, animals, and microorganisms) when averaged over time periods on the order of centuries. Although currently the release of fossil fuels dominates the buildup of greenhouse gases, land conversions from forest or grassland to agricultural uses have also contributed to the process.

New knowledge is needed on the positive and negative feedbacks between changes in land use, land cover, and ecosystems and whether the feedbacks will accelerate or reduce the effects on climate (National Research Council, 2001b). Past changes in land use and management are now being recognized as important terrestrial sources and sinks of carbon, and documenting such changes is essential for understanding the terrestrial carbon cycle. A substantial carbon source from forest clearing and a subsequent sink from land management have broad implications. Future research on the terrestrial sink may need to focus both on the history of past management and on ecosystem responses to future changes in climate and atmospheric composition. In studies on the carbon cycle, the interaction of global changes with land management should receive the same priority as the responses of natural ecosystems (Field and Fung, 1999).

Decisionmakers and scientists are actively exploring various methods to sequester carbon, including altering land use practices. Research is needed to determine the historical and current magnitudes of land conversions and their impact on the carbon cycle. Research scientists will need to use spatial datasets, including those acquired by remote sensing, to improve the precision with which the terrestrial carbon cycle can be measured and modeled. They will incorporate the processes of soil erosion and deposition, which were inadequately treated in previous analyses. As scientists achieve a better understanding of the physical linkages between land conversion and the carbon cycle, they will work with social scientists to model the social and economic alternatives for changing the human behaviors that lead to the buildup of greenhouse gases.

GAM research will seek answers to the following questions: What are the feedbacks between land use and land cover change, climate, and biogeochemistry? How does land use change affect regional weather and climate variability? What are the effects of climate variability on natural and human ecosystems? What have been the spatial and temporal patterns of the rates of carbon emission and sequestration caused by human activities related to land use change in the United States? How can land intensification occur without further deterioration of natural ecosystem services? Ultimately, what is the relationship between private land holders (small holders, in many cases in developing countries) and the ecosystem services "their land" provides? Can improved data and models contribute to a capability to predict the implications of projected land use change on the carbon cycle? Will an improved understanding of erosion and deposition of soil carbon, including carbon sedimentation in reservoirs, contribute to resolving the apparent imbalance in the global carbon budget (the so-called "missing carbon sink")?

Objectives: Quantify the effects of changing land use and land management practices on biogeochemistry (that is, nutrient enrichment, atmospheric CO_2) and regional climate variability (that is, modified land surface biophysical processes, altered temperature and precipitation patterns). Determine potential feedbacks among land surface change, regional climate variability, and biogeochemical cycles. Incorporate the effects of climate variability, including feedback mechanisms, into integrated assessments of ecosystem functioning. Evaluate the contribution of erosion and deposition to the rate of carbon sequestration or release in a variety of ecosystems. Document the existence, location, and magnitude of carbon sources and sinks resulting from historical and current land use change and management.

Goal 3: Understand the influences and interactions between infectious diseases and the environment.

Justification: Health problems caused by emerging infectious diseases are a growing concern worldwide among governments, scientists, the media, the popular press, and the public. With geographic distance and isolation no longer meaningful barriers, the opportunities for once-isolated diseases to spread have never been greater. The emergence of so many new diseases in humans in recent years is a result of our densely populated, highly mobilized, and environmentally disrupted world. Our vulnerability to such diseases is not going to go away. Dealing with emerging diseases requires the ability to recognize pathogens when they first appear and to act appropriately. Many emerging human diseases (zoonoses) are shared with wildlife species, where wildlife can act as a carrier or reservoir of human infection, often through invertebrate vectors such as mosquitoes. Since outbreaks are often evident in the nonhuman components of the environment before humans are affected, understanding environmental health is a prerequisite to protecting human health.

The USGS can monitor and model environmental and habitat changes, such as altered land use patterns and urban growth, which increase the rate of human exposure to zoonotic or vector-borne infections. Today, GISs, remote sensing satellites, and other technologies are providing scientists with the tools and the data to make clear the geographic relationships between environmental habitats of disease hosts, vectors, and pathogens, and the occurrence of disease. Although health professionals can effectively analyze the incidence and direct cause of illness, they lack the information and expertise to relate the occurrences of diseases with factors in the environment. Public health agencies need information on the source, occurrence (in space and time), transport, transformations, and fate of the pathogens that cause public health problems**.** They need to know what influencing factors, such as human population density and distribution, land and resource use, soil type, climate, animal reservoirs, and vectors, affect the risk of disease spread.

GAM research will seek answers to the following questions: How can we detect the presence of pathogens in the environment and measure and predict their extent and virulence? What methodological advances are needed to detect rare events, to determine the likelihood of an outbreak of infectious disease at a given place and time, and to determine risk when there is uncertainty in the underlying data? What are the roles and impacts of wildlife species on the maintenance and distribution of zoonotic diseases? What are the impacts of weather, especially temperature, humidity, and precipitation, on vector-borne disease transmission?

Objectives: Conduct a multiyear campaign of field research to obtain a better understanding of bird migration as a mechanism of virus dispersal, vertebrate host/vector relationships and range, and the current and future geographic distribution of West Nile Virus. Study how weather and environmental conditions influence the dynamics of potential disease vector populations**,** wildlife host distribution and abundance, and the interface between these components and human populations. Develop models that predict the spatial patterns of seasonal vector population dynamics, specify interaction with animal hosts (including humans), and estimate the disease risk to humans.

Goal 4: Analyze and interpret the record of land use dynamics that includes land use and land cover change to enhance understanding of the physical and social drivers of land surface change.

Justification: Historically, the macrodriving forces of settlement and the corresponding land use and land cover changes experienced in this country have been directly related to advances in transportation technology (Borchert, 1967). For example, improved transportation systems permitted the rapid westward expansion of agriculture beginning in the late 1700s. The contemporary forces are more diverse but relate to combinations of factors, including population, affluence, technology, economy, government regulations and policy, attitudes, and values (Von Hoffman and Felkner, 2002; International Geosphere-Biosphere Programme, 1993). Land transformation may be triggered by local forces (for example, a family decides to harvest timber on a woodlot to pay debts), regional and national forces (for example, government policies, such as wetlands legislation or crop subsidies), and global forces (for example, competitive advantages for producing food or wood). Driving forces commonly operate in combinations, which vary from place to place and from time to time. Understanding the driving forces of past land transformation is essential before future impacts can be projected or mitigated.

Natural and social driving forces need to be investigated within ecological regions nationwide in a framework that reflects the Earth's natural and human variation. These investigations will yield a determination of the relative importance of location, technology, the natural environment, and social preferences to explain land changes. Research activities must integrate remotely sensed images, socioeconomic data, and theories of land use dynamics to determine how and why these changes occurred. Research on the driving forces that produce the land dynamics of urban and ecological regions will allow public and private organizations to undertake planning and action with more knowledge of the impacts that their decisions will have. This research goal will also support Earth systems research that explores the consequences of human landscape modification. Lessonslearned from procedures and approaches developed for international applications will benefit this effort.

GAM research will seek answers to the following questions: What are the major natural and human-induced causes of land use change in different geographic and historical settings? What are the driving forces for land use and land cover change at the local, regional, and national scales? What are the most effective methods to link remotely sensed imagery to socioeconomic databases and land use dynamics theories? To what extent do relative location, path dependency, biophysical and social feedback, land resource institutions, and technology explain land use dynamics? To what extent can future land use changes be reliably predicted?

Objectives: Develop a framework for determining the local, regional, and global driving forces of land use and land cover change. Document the major driving forces of U.S. land use change for the past 100 years. Identify episodes of combined driving forces that had specific geographic and temporal signatures. Identify the major forces driving urban growth and sprawl development.

Goal 5: Conduct long-term monitoring of the state and trends of the Earth's land surface as critical input for regional and national policy decisionmaking.

Justification: The spatial and temporal pulses of land surface change that have occurred over the past 300 years are understood in only very general terms. For example, regional- and global-level changes of most land covers and uses, including such essential categories as forest and grassland cover, agricultural uses, and urban and suburban settlement, are still poorly documented (National Research Council, 2001b). An improved understanding of land use dynamics is critical to understanding the contemporary changes of ecosystems and to developing the baseline understanding needed to protect and mitigate future impacts to ecosystem health (International Geosphere-Biosphere Programme, 1993).

Human modification of the Earth accelerated dramatically at the onset of the Industrial Revolution. The Industrial Revolution started a long transition from an agrarian to an urban society. During this period, human population began to rise at an unprecedented rate, and the expanding population had greater demands for land and a more diversified economy. European settlement of the Americas increased. Although Native American land uses had modified the natural environment locally, the sheer number of European settlers started a transformation of ecosystems that continues today.

Assessing the status and trends of the Nation's land resources is essential for regional and national decisionmaking. Such assessment is the first step in understanding how ecosystems are influenced and affected by natural and human-induced changes. This information is needed to address significant national issues that include quality of life, the ecology of urban environments, ecosystem health, ecological integrity, water quality and quantity concerns, resource availability, vulnerability to natural hazards, human health, and altered air and land quality. These issues are of concern to the U.S. Government domestically as well as overseas, where scientific analysis is needed to guide investment decisions for development and humanitarian assistance.

GAM research will seek answers to the following questions: How has the land surface been changed by human use over the past 300 years? What are the national rates of land cover change, and how do the rates vary by region? What is the geographic variability of the sectoral, spatial, and temporal characteristics of land use and land cover change? What sectors and time periods are the most dynamic?

Objectives: Map the condition of the land surface at multiple spatial and temporal scales. Monitor and document changes in the land surface to determine how physical alterations of habitats influence ecosystem services and productivity. Develop a spatially explicit land use history of the United States from pre-European settlement to the present. Conduct detailed case histories, domestically and in developing countries that provide a means to understand the detailed mechanistic components of land use and land cover change.

Goal 6: Develop advanced techniques to monitor land surface change and ecosystem structure and function, in a spatially explicit fashion.

Justification: Geographic analysis and monitoring will require the measurement and observation at multiple scales of numerous variables that describe the land surface (for example, land cover type, land use, canopy density, ground cover type, and surface imperviousness) and ecosystem structure and function (for example, vegetation characteristics such as canopy height, density, and seasonally dependent characteristics, which may include fraction of photosynthetically active radiation, indexes of vegetation health and vigor, leaf-area index, fractional vegetation cover, net primary production, and water-energy-carbon fluxes). Field measurements, including site-specific studies to validate remote sensing products, will be needed to establish the baseline conditions of specific ecosystems. Greater use of remotely sensed data for synoptic monitoring will be needed, as will extrapolation of in situ measurements. Characterizing the temporal dynamics of large areas may be more practical with remote sensing technology than through traditional field approaches (Quattrochi and Pelletier, 1990). Monitoring and predicting change (for example, urbanization, deforestation) is one of the most important, yet difficult, contributions of remote sensing technology to studies of ecological change (Roughgarden et al., 1991). The transition from conventional mapping studies to a more analytical endeavor based on theory and modeling will be difficult. This transition should be aided by growing attention to the role of land surface change and ecosystem processes in fields such as landscape ecology and the development of tools such as GISs (Riebsame et al., 1994).

GAM research will seek answers to the following questions: What are the fundamental spatial and temporal scales upon which to monitor ecosystems? What methodological advances are needed to map ecosystem structure and function and land surface change in a spatially explicit fashion? What spatial frameworks and overall monitoring design should be implemented to sample ecosystems? What ecosystem and land cover characteristics should be measured, and how should they be captured and validated?

Objectives: Develop criteria and indicators of land surface condition. Develop GIS, remote sensing, and other techniques to improve the accuracy and efficiency of land use and land cover mapping, as well as the study of ecosystem structure and function. Develop criteria for validating remote sensing products, including map accuracy assessment. Study the feasibility of research on improving fuel moisture content estimation and fire-scar mapping.

Goal 7: Develop methods to communicate research results and assist decisionmakers with ecosystem strategies and sustainability.

Justification: The real world is complicated, and there are no simple solutions to vexing environmental policy issues. Natural ecosystems and human social systems are complex and interdependent. To gain a better understanding of these complex systems, it is necessary to take an interdisciplinary approach and consider a full range of values and interests that include the scientific, economic, political, social, cultural, ethical, and aesthetic. Citizens and decisionmakers are finding themselves having to weigh both sound science and community values in making choices and tradeoffs about land use and environmental resource management. The USGS needs to develop new methods and products and explore means of combining different ways of knowing and learning to better communicate research results and assist citizens and policymakers with these difficult decisions. It is necessary to take a problem-focused, rather than a discipline-focused, approach that cuts across USGS discipline boundaries and links many of the programs within the USGS. The research will be coordinated with programs of other Government agencies, universities, and institutions.

Applying scientific information to decisionmaking and public policy requires the application of decision support system tools that incorporate data, analyses, predictive models, and advanced visualization techniques that provide alternative policy scenarios for decisionmakers to consider. Facilitating the integration of scientific and economic information with social and political values helps achieve balanced, informed solutions to environmental and resource policy issues. To do this, scientists will need to develop a better understanding of the decisionmaking process. They also need to recognize that many land management decisions require consensus building and are inherently political.

The impact of policy and management strategies on the physical landscape and the human environment is determined in large part by rules allowing, or restricting, land use. Land use patterns represent a distribution of investments in both physical and human capital that is exposed to risks from environmental and natural hazards. Identifying the relationship between the physical environment and the implicit social and economic environment, as regulated by land use policies, will allow a better assessment of environmental hazards and losses and improved risk-management policies and hazard mitigation planning. Research aimed at this goal will develop the analytical tools to model these relationships.

The USGS is currently developing a natural science/economics land use portfolio methodology to communicate environmental risk. Environmental risk maps are developed by statistical integration of demographic, environmental, and socioeconomic data. Environmental hazard susceptibility is estimated as a probability of a physical state change from the current state of the environment in a community or region. The physical state change can be triggered either by a dynamic natural physical process or by a human-induced environmental change. In most cases, the maps represent the susceptibility to an adverse physical change. Environmental risk maps have been designed as a quantitative approach to translating natural science information to a metric for policy decisions and to providing the core element of a GIS-based risk communication instrument to assist private and public sector stakeholders. Examples of application areas include estimates of flood inundation, the significance of rainfall anomalies for enhanced malaria transmission, and the extent and impact of drought upon agricultural systems.

GAM research will seek answers to the following questions: To what extent can land use and environmental policy and management be based on scientific information in combination with social and political factors? Is there a systematic relationship between the relative influence of scientific information on policy and management decisions and other national and regional social, physical, and economic information? Will scientific information actually have an impact on land use through the mitigation of natural and environmental hazards? What economic benefits accrue when decisions supported by scientific information are applied to high-risk areas and development is constrained?

<u>Objectives</u>: Develop GIS-based decision support tools that integrate earth science information and economics to model complex human and natural systems related to specific environmental or risk issues. Develop community-based participatory procedures that involve scientists, citizens, stakeholders, and users of knowledge in seeking consensus on decisions to vexing environmental policy issues in a world put at risk by the unintended consequences of technological change and population growth. Determine the usefulness of science in land management decisionmaking.

Linked Goals

The results of many GAM 5-year goals support the results of goals in other Bureau programs. GAM investigations provide fundamental socioeconomic, land use, and land cover information that provides a foundation for the biologic, hydrologic, and geologic process studies of those programs. The GAM Program has identified and linked several of its science goals to the goals of the CTM, LRS, Status and Trends, Ecosystems, Earth Surface Dynamics, and National Water-Quality Assessment Programs.

For example, the CTM Program assembles and maintains a seamless, nationally consistent, vertically and horizontally integrated set of basic geographic data. The program also develops tools and applications that promote *The National Map* as the geospatial underpinning for other Federal mapping activities and those of other public and private organizations. The CTM Program provides baseline geographic data for many GAM research studies. The CTM Program work in maintaining, archiving, and disseminating spatial information will support GAM goals in information dissemination and decision support. GAM goals, in turn, contribute scientific value and knowledge to the spatial content of *The National Map* by demonstrating the value of *The National Map* data products in case study applications that address environmental, natural resource, and economic issues. GAM goals will support CTM goals by providing feedback on data requirements and demonstrating uses of *The National Map* through regional applications monitoring rates of change and environmental consequences. GAM goals also support CTM by developing decision support tools and models that users can integrate with *The National Map* to deal with environmental, natural resource, economic, and land management issues. GAM's analysis of change serves a valuable role in identifying areas for updating *The National Map.*

The LRS Program develops an understanding of the spectral, radiometric, spatial, temporal, angular, and stereographic information content of remotely sensed data as related to the Earth's surface and land surface processes. The LRS Program also conducts validation studies and investigates advanced algorithms for land cover mapping and land surface characterization. These activities provide the GAM Program with essential information on the application of remote sensing data and algorithms. The GAM Program in turn supports LRS program goals with valuable feedback and additional testing and validation of remotely sensed data for detecting change detection and monitoring ecosystem health. Feedback includes user requirements on data needs for advanced remote sensing products and sensor design.

The Status and Trends Program determines rates of change and trends in the Nation's biological resources. The program also develops monitoring strategies for regional and national assessments. GAM goals that support Status and Trends goals are those that will contribute nationally consistent descriptions of current land surface and land use conditions to draw linkages with biological observations.

The Ecosystems Program conducts research to understand the natural processes that control environmental conditions, such as animal and plant productivity, the health of aquatic communities, and local to global biodiversity. Research activities include assessing ecosystem vulnerability to the effects of natural and human-induced environmental change and providing information to mitigate these effects. Research topics include the ecology of wetlands, forests, arid lands, and grasslands, disturbance and landscape ecology; modeling of ecological systems and quantifying ecosystem services; restoration and fire ecology, and global change. GAM goals will offer an understanding of the relationships among land use changes and environmental quality essential for the Ecosystems Program to assess ecosystem goods and services.

The Earth Surface Dynamics (ESD) Program focuses on understanding the interactions among changes in climate, human activities, Earth surface processes, and ecosystems. The program supports multidisciplinary studies of past environmental and climatic changes, monitors present conditions and ongoing changes, conducts process studies that explore the sensitivity of the Earth surface and associated ecosystems to natural and human-induced changes, and forecasts potential future changes and their effects (particularly on public lands and waters). These studies provide an integrated long-term perspective on the causes and effects of environmental and climatic changes. The common interests and links between ESD and GAM are obvious. The results from one program will support the work of the other in many areas. Collaboration and coordination between the programs promises to enhance and broaden the scope of USGS research.

The National Water-Quality Assessment (NAWQA) Program assesses the status and trends of the Nation's water quality. Study unit assessments are used to provide a national synthesis on the condition of the Nation's streams and ground water. Links between GAM and NAWQA are primarily related to understanding land use and land cover change, in particular the rates, trends, and driving forces of this change.

Shared Goals

Shared goals are goals that are common to two or more programs. The GAM program shares goals with at least three other programs.

GAM and the Status and Trends Program share goals to assess and report the condition of the Nation's land and biological resources, respectively. Both intend to develop a national framework for monitoring and integrating information at multiple spatial and temporal scales. Both envision developing methods, protocols, and technologies for inventorying and monitoring change in land and biological resources.

GAM and the Ecosystems Program share goals for national monitoring and synthesis. Common goals include determining the sensitivity of biological resources nationally and by specific geographic areas to detect early ecosystem changes. This effort includes quantifying the role of scaling in understanding the spatial and temporal responses of change. The GAM Program and the Ecosystems Program also share a common goal to quantify and understand patterns of temporal and spatial variability in key ecosystem components and processes. These patterns are key for understanding the present condition of natural resources and predicting likely future changes.

The GAM and the ESD Programs share a goal of providing scientific support and perspectives for policymakers and land resource managers. Both programs emphasize the need to study the impacts of land use on ecosystems. Both focus on monitoring, modeling, and forecasting the impacts of environmental change on landscapes. Common interests and goals include the following: involve reconstructing land use histories, records of fire frequency, climate change, and shifts in plant communities to provide a deeper perspective on current environmental trends, monitor landscape processes to understand biogeochemical cycling of carbon and nutrients, monitor selected indicators of landscape change, understand rates of key processes and landscape responses, and develop predictive models of complex interactions and feedback mechanisms among climate, land surface, ecologic, hydrologic, and societal systems.

Expected Outcomes and Performance Measures

The expected outcomes and performance measures for the GAM Program are rooted in six key documents. They are the GAM 5-Year Program Plan, Director's Annual Guidance, Annual Program Direction, Annual Work Plans, Project Plans, and Annual Accomplishments. The GAM 5-Year Program Plan must align with the USGS Strategic Plan to ensure that GAM is contributing to regional and national priorities of interest to the USGS, DOI, and the public. This process for establishing GAM Program priorities is further refined by ensuring that the GAM Annual Program Direction and GAM Project Work Plans are consistent with the USGS Director's Annual Guidance. As part of the process to determine the Annual Program Direction, the GAM Program will also seek information from the three USGS Regions and GAM scientists concerning any additional regional, national, or innovative research priorities that should also be considered for funding as projects or tasks within the GAM Program.

Given the information resulting from this process, plus deliverables promised in approved research proposals, Project Plans including task descriptions will define the expected outcomes, scientific deliverables, and performance measures for each project. In this context, a project deliverable could represent an expected outcome, performance measure, or both. Information on each GAM research project, component tasks, and expected outcomes will be recorded in the Bureau's Budget and Science Information System (BASIS), which is the Bureau system for project planning, project- and account-level budget planning, fund management, and account balance reporting. GAM project chiefs are responsible for entering individual project work plans, budget, expected outcomes, and deliverables into the system. At the end of each fiscal year, the project chief will submit written documentation, which summarizes the accomplishments, outcomes, and deliverables completed by the project. For example, expected outcomes and deliverables could include publications in peer-reviewed scientific journals, USGS publications (Professional Papers, Circulars, Bulletins, Open-File Reports, Fact Sheets, and so on), conference papers and posters, GIS datasets, Web sites, briefing packages, and proposals. Projects can communicate project outcomes, accomplishments, relevance, and deliverables by a variety of means (scientific papers, Web sites, workshops, forums, briefing packages, and so on) to USGS and DOI resource managers and policymakers and the public. However, it is imperative that project chiefs and task leaders ensure that Annual Work Plans promise expected outcomes, deliverables, and performance measures that are consistent with project resources, and take into account potential uncertainties that can either impede progress or create "new opportunities" inherent within any scientific research endeavor.

GAM Program management will routinely monitor and evaluate expected outcomes and deliverables, including the quality, timeliness, and relevance of products as defined by annual work plans and Annual Accomplishments. Feedback from Bureau officials and others will be used to improve the outcomes and products of projects. GAM Program Managers and Project Chiefs will routinely assess the scientific results in terms of how well the GAM Program is contributing to the Nation's priorities, as well as the scientific relevance of its accomplishments. The GAM Program will determine how the expected outcomes and deliverables are making a difference to other USGS programs and policy in DOI and elsewhere. Other questions for determining performance include: Are the projects within the GAM Program producing scientific results and products that satisfy the program's mission requirements? Are projects making direct contributions to the missions of USGS and DOI? Are the Program's outcomes and findings contributing to the science priorities of the USGS and DOI, as communicated in the USGS Director's Annual Guidance? Are the scientific results and products of the GAM Program recognized by the USGS and broader scientific communities as representing sound scientific contributions of relevance to USGS, DOI, regional, and national priorities? Does the GAM Program include projects that are producing innovative and "leading edge" scientific results, which provide the basis for future USGS and DOI policy directions? Is the Status and Trends Report of the GAM Program recognized as a premier USGS scientific publication of relevance to USGS, DOI, regional and national policy?

Partners and Customers

The GAM Program collaborates with and provides information to a broad assortment of Federal, State, and private sector interests that look to the USGS for a nationally consistent description of current land surface and land use conditions for the Nation. These partners and customers seek to enhance their scientific understanding of land surface change to better manage public lands, develop effective policy, manage resources, and convey to the public the impacts of their decisions.

Primary partners are DOI Bureaus and Federal agencies, such as the U.S. Department of Agriculture, EPA, and USAID. An increasing emphasis will be placed on partnerships with DOI Bureaus with land management roles, such as the Bureau of Land Management (BLM), the National Park Service (NPS), and the Fish and Wildlife Service.

The primary partners for goals 1, 4, 5, and 6 are groups with needs for land surface characterization, with particular emphasis on its dynamic nature. In the past, this has included Federal agencies with geospatially based activities, such as the EPA, the Bureau of the Census, and the National Aeronautics and Space Administration. An increasing emphasis will be placed on partnerships with Department of Interior bureaus and others with land management roles such as BLM, the NPS, the Bureau of Reclamation, the U.S. Forest Service, and the U.S. Army Corps of Engineers. In addition, the program will work with partners in other USGS programs such as the GAP Analysis Program, National Water Quality Assessment Program, Earth Surface Dynamics Program, and Land Use History of North America Program.

These four goals (1, 4, 5, and 6) also support partners involved with GAM's natural hazards activities. Other organizations, national and international, public and private, engaged in hazard identification, mitigation, and recovery efforts, use GAM land surface change products to help identify and mitigate natural hazards. These include the Federal Emergency Management Agency, NOAA, the Red Cross, EPA, and the office of U.S. Foreign Disaster Assistance. A particularly strong partnership will be maintained with the National Interagency Fire Center.

Participants in the program under goal 2 (Impacts of Land Use Change on Climate Variability and Biogeochemistry) will partner with other agencies in the U.S. Global Change Research Program and future climate system science initiatives. There are opportunities for partnerships with agencies in NOAA, such as the National Weather Service, particularly because of an increased awareness in the atmospheric sciences community that the potential of GIS technology has not been fully exploited.

Participants in the program under goal 3 (Impacts on Human Health) work closely with the Center for Disease Control, as well as with local and State public health organizations in States with disease focus sites, which rely upon GAM investigations and data to understand the impacts of land change on human health. Internationally, this is exemplified by work on Rift Valley Fever in Africa and support to the Roll Back Malaria initiative of the World Health Organization.

Participants in goal 7 (Communicating Science to Decisionmakers) work closely with State and local agencies that depend on land use and related natural and social science information collected by this and other USGS programs for making decisions about local and regional issues. Partners include the Consensus Building Institute, Collaborative Decisions, National Center for Ecological Assessment and Synthesis, Nature Serve, Association of Bay Area Governments, and

Tahoe Regional Planning Agency.

In the international arena, GAM products can greatly assist USAID in implementing landscape-level models and climate forecasts in humanitarian responses (for example, Afghanistan and Africa), as well as in long-term assessments of sustainable management in the Sahel, for example. Other partners include the U.S. State Department, the United Nations, and nongovernmental organizations, as well as those mentioned under goal 3.

The GAM strategy will be to increase the participation of partners through collaboration on a variety of resources. Reimbursable funding is only one strategy for sharing resources. Other resources that can be shared include expertise, data, equipment, facilities, and goodwill. It will be the strategy of the GAM Program to increase the resource-sharing partnerships in which its scientists participate. Agreements that allow organizations to share resources include cooperative research and development agreements, technical assistance agreements, and memoranda of agreement. It will be the GAM strategy over the next 5 years to increase the number of agreements that bring partner resources to the GAM Program.

Funds appropriated to the GAM Program are used to manage the ensemble of scientific studies, to develop new partnerships, to represent the USGS in international scientific entities, and to carry out USGS mission-critical activities that do not provide partnering opportunities. Combining partner resources with these funds will enable the GAM Program to reach greater program strength while contributing to land use trends that are of interest to partners and customers.

In the past, GAM has been associated with a wide variety of academic institutions both in the United States and around the world. Given the science basis of the GAM Program, the strategy is to increase cooperative relationships with academic institutions. The GAM Program maintains and plans to strengthen existing ties to academic institutions through grants, cooperative agreements, collaborative projects, onsite faculty, and job opportunities for graduate students. The GAM Program is closely affiliated with the Association of American Geographers. Use of the National Research Council Fellowship Program adds expertise to the GAM Program's scientific capabilities.

V. Program Review

The GAM Program will conduct several types of program reviews. A scientific review will be conducted every 2 years. The program's goals and objectives will be reviewed and modified accordingly. Every 3 years a peer review of the program will be conducted by a panel of 10 leading professionals. The panels recommendations will contribute to the 5-Year GAM planning process. These reviews will follow Bureau policy on review procedures and the requirements for achieving and reporting on the Bureau performance metrics and the Government Performance and Results Act (GPRA).

The GPRA requires all Federal agencies to define long-range goals, establish annual performance targets, and report on achievements of those targets. The goals of the GAM Program are linked to the Bureau Strategic Plan in terms of critical business activities. These goals emphasize the impact of program accomplishments on issues critical to the Nation, and the annual measures are structured to include reporting accomplishments by each part of the program.

Once the GAM 5-Year Program Plan is completed, a process of review will begin at a detailed level by cost centers and gradually move to a broader review by upper level management until it is determined that the plans are meeting goals of the organization.

Cost Center Chiefs in the Regions and Headquarters review the draft BASIS+ project plans and proposals to verify that planned work is scientifically and fiscally sound. The completed plans are reviewed by Regional Executives (REX) to ensure the health of the cost centers and that the Regional science and operational goals are being met and the performance measures addressed. Bureau Program Coordinators also review project information during this time to ensure that program goals will be accomplished as needed and coordinated with REXs on any needed changes. Regional Directors review summaries of the plans to access regional financial and operational health and to ensure that regional goals are met, high-priority issues have been addressed, Bureau guidance has been adhered to, interdisciplinary and interregion coordination has occurred, and performance measures have been established. Similarly, the Deputy Director, with the Associate Directors, Geographic Information Officer, and Chief of APS, review plans for the headquarters cost center. The Bureau Program Committee approves the overall plan for work. At this point, annual planning is complete and approved, contingent upon appropriated funding for implementation.

VI. Expertise and Capabilities

Staff and laboratories in USGS's National Mapping Discipline embody broad expertise in geographic, biologic, climatic, soil, and hydrologic processes. Notable are long-term perspectives provided by understanding land use history. Capabilities span the scientific fields of climatology, hydrology, process modeling, remote sensing science, biogeochemical cycling in soils, topographic mapping, and GISs. Scientific support includes analytical labs, database management, GIS, remote sensing data analysis, visualization techniques, and science policy analysis. The USGS is well positioned to undertake broad-based landscape studies such as those outlined here.

The GAM Program is committed to a long-term goal of developing and strengthening the scientific capabilities of its current and future workforce of scientists, managers, and support staff. The GAM Program seeks to further the ability to predict the consequences of human-induced or natural processes. To achieve this, GAM needs staff with expertise in modeling, analysis, and predictive methods. The GAM Program seeks to communicate societal impacts. This will require us to use new and novel communication channels to effectively reach society with the results and conclusions of our monitoring, research, and analysis efforts.

The GAM Program will require the capability to monitor and collect new types of data. There will be a need for a variety of specialized field data-collection capabilities, such as off-road vehicles, ground-penetrating radar, coring devices, boats, and digital cameras. Aspects of these new technologies are being facilitated by the Global Development Alliances that USAID is forging with USGS assistance for field applications in developing countries but relevant to national needs as well.

It is essential to maintain continuity in USGS's broad expertise in land use and land cover mapping, trend analysis, database management, and information science. It is equally essential to develop or supplement capabilities in the following areas:

- Geographic information science
- Environmental simulation modeling
- Spatial statistical analysis
- Biogeochemical cycling
- Climatology
- Remote sensing science
- Hydrology
- Landscape ecology
- Ecosystem processes.

Over the next decade, the program will direct increased resources to improving the usefulness of geographic maps, both through technical advances in digital display and interpretation and through the inclusion of "value-added" information that is relevant to public use, such as engineering and hydrologic properties of map units.

GAM will advance the use and technical development of geographic information systems and three-dimensional visualization as tools for landscape mapping and for transport of geographic information into modeling geologic, hydrologic, biologic, and geographic processes.

VII. Facilities

GAM scientists, managers, and support staff will be geographically dispersed across the country organized into Geographic Analysis Teams (GATs) with either a local, regional, national, or international scope. The GA Teams will use existing USGS facilities. The GAM Program will need to provide private offices with access to a common area, lab space, conference rooms, and a library for each GAT. The GAM Program needs to provide high-speed Internet access to facilitate the communication and sharing of information between GATs and other USGS science teams.

The GAM Program currently maintains small field offices in Anchorage, Portland, and Tucson. These offices have proved extremely effective in building local support for the GAM Program and in expanding the "customer base". These offices will be expanded and additional offices established in cities such as Tampa Bay, San Antonio, and Chicago.

The recent movement of offices in Menlo Park should reduce space charges there. Considerable effort will be needed by managers to maintain programmatic cohesiveness between GAM personnel.

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