A LAND USE AND LAND COVER CHANGE SCIENCE STRATEGY

Summary of a Workshop
held at the Smithsonian Institution

Nov 19-21, 2003

Organized by the US Climate Change Science Program (CCSP) Land Use Interagency Working Group (LUIWG)

Edited by

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Background to the Document

A workshop was organized by the Land Use Interagency Working Group (LUIWG) of the US Climate Change Research Program (USCCRP) on November 19-21, 2003 to bring together representative university and federal agency scientists and stakeholders to expand on the Land Use and Land Cover Change components of the Climate Change Strategic Plan. The attendees were charged with reviewing the Land Use Chapter of the Strategic Plan and further developing the research elements, focusing on what needs to be done, providing an indication of priorities for the science and stakeholder communities and a broad assessment of resource levels and timing needed to achieve the various research goals. This document has been reviewed by the meeting attendees and may be used as input by the LUIWG in the development of its program implementation plan."

CONTENTS

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LAND USE AND LAND COVER CHANGE SCIENCE STRATEGY

Workshop Summary

The Purpose of this Document

The US Climate Change Science Program (CCSP) is a combined initiative of the US Global Change Research Program and the Climate Change Research Initiative. In 2003 CCSP developed a Strategic Plan. The Strategic Plan laid out a ten-year research agenda and outlined the research elements and cross element integration aspects of the climate change program. As part of the process of developing a concerted research plan a Land Use/Land Cover Change Interagency Working Group (LUIWG) was formed consisting of representatives from the participating Federal Agencies with research activities in the area of land use change. This group was responsible for developing the Land Use/Land Cover Change chapter of the Strategic Plan (Chapter 6) and will be responsible for coordinating the implementation of the research agenda.

The Land Use and Land Cover Change element of the CCSP is a new element of CSSP and of direct and immediate relevance to a wide variety of stakeholders. Land management decisions and actions provide a direct link to many of the issues addressed by the CCSP. Stakeholders guide many of the societal needs for research on land use and land cover and, in turn, scientific research on land use and land cover provides important understanding and knowledge that is useful for decision-making and management. The involvement of stakeholders is central to the success of the land use and land cover research described in the strategic plan and this science strategy and scientists and stakeholders will need to develop and maintain active partnerships.

The Land Use chapter of the Strategic Plan lays out the major areas for research in land-use and land-cover change science, but it does not contain details, such as an analysis of feasibility or a sense of prioritization within the research element. A workshop was therefore organized by the LUIWG in November 19-21, 2003 to bring together representative university and federal agency scientists and stakeholders with an interest in the program. The objective was to expand on the components of the outline strategy and develop a more detailed science strategy.

Forty people attended the workshop hosted by the Smithsonian Institute. The scientists attending were charged with reviewing the Land Use Chapter of the Strategic Plan and further developing the research elements, focusing on what needs to be done, providing an indication of priorities for the science and stakeholder communities and a broad assessment of resource levels and timing needed to achieve the various research goals. This summary provides an overview of the findings of the meeting under the chapter headings of the full report.

CHAPTER 1: INTRODUCTION

Future patterns of land use and land cover must be understood at a range of spatial and temporal scales to characterize and predict the behavior and impacts of the Earth's land use, climate, carbon, water, ecological and socioeconomic systems. Scientific research on land use and land cover change has both resource management and strategic relevance.

Current research for land use and land cover change is spread across various agencies addressing both basic and applied science questions. Basic science questions for example focus on: i) the dynamics of change in land use and land cover; ii) the integration and feedbacks between land use systems and climate, socioeconomic and ecological systems; iii) the resilience, vulnerability, and adaptability of coupled natural and human systems; iv) spatial and temporal scale issues; and v) accuracy issues and predictive skill. Applied science questions for example focus on: i) evolving national and international public and private land management questions and decisions that call for new data and information and improved scientific bases for decision-making; ii) the interpretation and communication of scientific knowledge for adaptive management of land use systems; iii) human and socioeconomic responses to change; and iv) explicit management of uncertainties and definition of the limits to applicability of change projections and other analyses, particularly as translated into decision support. Applied science questions need to address fundamental questions on the impact of land use change on the provision of ecological goods and services such as food, water supply and biodiversity as well as human well-being, sustainability and land degradation.

The more applied aspects of the research program for land use and land cover change need to meet stakeholder needs.. In this context, stakeholders are defined as those who can benefit from an improved scientific understanding of land use. To ensure relevancy of the applied research, stakeholders must be involved in the research at all stages including formulation of research questions and research teams. Land use change, human health, biodiversity, and regional stability are important considerations and land use planning is a priority issue for most countries. Land use related issues such as food and water security and human health are a high priority for developing countries. The program that is developed will need to keep a balance of national and international research.

Chapter 6 of the Strategic Plan identified two overarching research questions:

1. What processes determine the temporal and spatial distributions of land cover and land use at local, regional, and global scales, and how and how well can land use and land cover be projected over time scales of 5-50 years?
2. How may changes in land use, management, and cover affect local, regional, and global environmental and socioeconomic conditions, including economic welfare and human health, and taking into consideration socioeconomic factors and potential technological change?

The research program to answer these questions needs to be based on a thorough understanding of the physical environmental, ecological, economic, social, cultural, and decision processes that characterize and control land use and land cover systems. Observations, monitoring, data management and analysis, modeling and projection, assessment and evaluation of consequences and impacts are essential components of the research and must be coupled with other program elements of the US Global Change Research Program.

The following sections elaborate on the five LULCC research questions identified in Chapter 6 of the Strategic Plan. Specific goals are identified with their associated time-line, priority and cost. Priority 1 is assigned to those goals which are critical or need an immediate start to provide a foundation for the ten year program. Recognizing that not all the research can be funded at once, Priority 2 means the research is needed but these research activities can implemented at a slower rate or start later than Priority 1. Costs are given as an estimate of what would be needed to address each question in a comprehensive way during the ten year program. The tasks and estimated costs are summarized in Table 1. The overall level of funding needed for this multi-agency research program is estimated to be c. $16 Million a year for 10 years.

CHAPTER 2: CHARACTERIZING HISTORIC AND CURRENT LAND USE AND LAND COVER ATTRIBUTES AND DYNAMICS

Improved scientific knowledge of historic and current land use and land cover changes is required as a basis for understanding the dynamics and trends in land use and land cover change and increasing our understanding of the processes by which changes occur and the impacts of land management and decision-making on change. This characterization provides a baseline for monitoring land use and land cover change; developing understanding that allows models to be developed that project land use and land cover change into the future, and for an improved ability to couple both land use and land cover with research in climate, ecosystems, the carbon and hydrological cycles, and human systems.

Specific Research Goals

2.1. *Improve the specification of land use/land cover data requirements from the broad range of users (2 years - Priority 1).* LULCC scientists and stakeholders and scientists in other elements of the CCSP require data on land use and land cover. These users have varying requirements of the types of information required about land use, land management and land cover, spatial and temporal scales required, accuracy, and standardization and consistency across time and space scales. An improved specification of data requirements is needed to ensure that the necessary data sets are being provided and to guide the development of the emerging global integrated observing systems.

2.2. *Achieve continuity in ground-based and satellite-derived land cover observations (Ongoing - Priority 1).* Consistent long term observations from multiple satellite sensors and ground-based sources are a prerequisite for quantifying land use and land cover change. Reliable land use and land cover data can only be developed if data records are

derived from repeated and consistent observations and science-quality measurements. Continuity in data collection is a priority goal for the land use and land cover element placing an emphasis on establishing operational data collection systems and a commitment from federal agencies to provide the data. In addition to ground-based measurements, a combination of long-term satellite observations is needed, for example moderate resolution data (250m -1km) for mapping of land cover and detecting changes in land cover, vegetation and crop condition, high resolution data (10m-30m) for characterizing and measuring land cover change and sample hyper-spatial resolution data (1m-3m) for characterizing land use. Particular attention is needed by the USG to provide an uninterrupted global time series of Landsat class measurements in an operational framework. International cooperation can enhance the availability of both satellite and ground-based measurements, for example through the Global Observation of Forest Cover/Global Observation of Landcover Dynamics (GOFC/GOLD) project in the framework of the Integrated Global Observing System (IGOS).

2.3. *Enhance ground-based, systematic, spatially explicit observations to understand land use (On-going – Priority 2).* Characterization of land use requires the integration of ground-based survey and census data with remotely sensed data. This requires ground-based data to be as disaggregated and spatially explicit as possible. Significant progress needs to be made to make available spatially explicit ground-based land use data. This will require the cooperation of federal agencies that have so far had limited input to the global change research program.

2.4. *Improve access to spatially explicit land use data for the land use science research community (On-going- Priority 2).* Making spatially explicit socioeconomic and land use data available to the research community will improve the quality and quantity of research on land use and land cover change but raises legal and ethical issues associated with data and confidentiality. There are a number of proposed, but largely untested, solutions to confidentiality issues, such as creation and designation of a 'safe room', explicit data security plans associated with a given institution, transformation of the data such that a particular parcel, person, or group cannot be identified with precision. Investigators need to be encouraged and possibly required through funding, to make data available to a broader community, perhaps through greater use of dedicated data clearinghouses.

2.5. *Develop standardized land use data sets and models that are accessible to both researchers and stakeholders (6 years - Priority 1).* Land use and land cover data sets serve important roles in several sectors of CCSP research, providing model inputs and a means to assess the impacts of different land management strategies. Periodic global inventories of land cover of known accuracy need to be generated using standardized methods and made widely available. Most countries need to monitor land cover change on an annual basis. Standardized LULCC models need to be developed and made broadly available to scientists and stakeholders to facilitate exploration of the impacts of different land management scenarios.

2.6. *Education and training to develop a research community with competency in land use science (On-going – Priority 2).* For LULCC research, the need for integration of skills, theory, data, and techniques from multiple disciplines, coupled with the relative recent application of land use science in some disciplines, raises an important set of issues involving education, training and funding. Attention needs to be given to ensure a supply of scientists trained in interdisciplinary research, for example trained in both remote sensing and ground-based approaches to studying land cover and land use change. A program addressing land use at the different levels of the education system is proposed, including introduction of land use science into the Kindergarten to High School educational arena, development of a land use science curriculum at the graduate level and short-term graduate training.

2.7. *Develop systematic approaches to the acquisition, compilation, organization, and accessibility of data on past changes in land cover and land use (6 years – Priority 2).* The provision of consistent time series of historical data is needed to enable the testing and comparison of models of land use change. Coordination of this activity with similar activities in partner international programs e.g. IGBP is strongly recommended.

Timeline and Costs

Total cost to realize this research component on characterizing historic and current land use and land cover characteristics and dynamics projected over the ten year period is c. $40 million, or $4 million per year. This would cover the research costs but does not include the cost of the underpinning satellite or in-situ data collection.

CHAPTER 3: UNDERSTANDING THE PRIMARY CAUSES OF LAND USE AND LAND COVER CHANGE

Introduction

The ability to forecast land use and land cover change and, ultimately, to predict the consequences of change, depends on our ability to understand the past, current, and future drivers of land use and land cover change. These factors, as well as other emerging social and political factors may have significant effects on future land use and land cover. Patterns of land use and land cover change, and land management are shaped by the interaction of economic, environmental, social, political, and technological forces on local to global scales. We must understand the primary modern and possible future drivers of land use change and their interrelationship with land management decisions and resource policies to develop projections of future land use and management decision outcomes under a range of economic, environmental, and social scenarios. Improved process-based models of land use and land cover change dynamics in space and time are also needed and these should combine field-level case studies for analysis of processes and management systems, statistical studies for large regions, and empirical analyses using remote sensing at local to global scales. Linking between processes at these various scales will be an important research area.
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Specific Research Goals

3.1 *To understand the causes of land cover and land use change well enough to project change into the future and to assist policy makers in the design of potential interventions (Ongoing - 2 years for initial synthesis, Priority 1)..*

Causes of land use and land cover changes have been studied at different temporal and spatial scales and in different disciplines. The research community must synthesize existing studies to improve generalization, conceptualization, and theory of land use change science. Within the next two years a multi-disciplinary synthesis is needed to expose previous work that has originated in different disciplines to a wide inter-disciplinary audience. These syntheses should also identify information needs for global land use change assessments. Priorities should be set so that key policy-relevant questions are addressed.

Funding for this work should combine both top down and bottom up approaches. Research funds should provide individual investigators with the opportunity to propose original approaches to study land use and land cover change, as well as Requests For Proposals (RFPs) focused specifically to support the development of the community goals defined in this Science Strategy. Local process studies examining the drivers of land use change at the local scale need to be set in a broader conceptual framework.

3.2 *To improve feedback between those collecting and processing data and those analyzing and modeling land use and land cover changes (On-going, First Workshops completed in 2 years, Priority2).*

Improvements in investigating drivers and modeling of land use and land cover change will depend significantly on improvements in the available databases. Efficacy of data collection and processing efforts can be enhanced by stronger interaction between producers and users of the data. Feedbacks between these groups should be encouraged, given the many potential demands for land use and land cover data. A series of workshops involving data collection specialists, database experts, and users of the data should be initiated to establish a better match data and information requirements and availability. The first workshops should be completed within two years and where possible should build on existing structures.

3.3 *To improve understanding of the interrelationship of drivers of land use and land cover, land management, and resource policies, for use in environmental, economic and social scenarios (On-Going, 2 years for Initial Assessment, Priority 2).*

A key research question is whether the major drivers and determinants of land use and land cover will change in the future, under a range of different environmental, economic, and social scenarios. Integration across disciplines will foster investigations of adaptation and mitigation options taking account of any significant interactions among causes of land use and land cover change and variability (both physical and socioeconomic). The current state of knowledge for understanding such interrelationships should be documented within the next two years, including how information can be used in risk

assessments. To enhance the relevance of the research, scenario development needs to be developed closely with stakeholders. This work could be carried out with a series of workshops.

Timeline and Costs

Total cost to realize this research component focused on improving understanding of the primary drivers of change through case studies, syntheses, workshops over the next ten years is $12.5m, or an average of $1.25m per year.

CHAPTER 4: PROJECTING FUTURE LAND USE AND LAND COVER PATTERNS AND CHARACTERISTICS

Introduction

The research needed to make projections of possible future patterns and characteristics of land use and land cover change will be based on an understanding of both the historical and contemporary causes and rates and drivers of land use and land cover change. Research is needed that develops new systematic methods and study designs for land use change modeling, incorporating the forces of change that operate at different spatial and temporal scales. Predictions of land use and land cover change provide important scientific and practical outcomes providing insights into possible consequences of change for human and natural systems and the interaction of these systems, and facilitating improved decision making for management of land and of systems in which land dynamics play an active role, such as ecosystems, and water and carbon cycles. A number of types of models of land use and land cover are being used for explanatory and/or predictive purposes.

Prediction from models is based on a set of assumptions about the nature and functional form of the drivers of land use and land cover change into the future. The simplest approach is to assume that the drivers and their functional relationships are similar to those of the recent past. Evolutionary models applied in the social sciences to represent human adaptability in the face of a changing environment need to be explored as a means to relax the stationarity assumption in land use and land cover models. Predictions will need to be made in the context of well-defined and reasonable scenarios.

Challenges for the land cover and land use modeling community include a) determining the spatial and temporal information and scales needed to project land use change at the national and regional levels, b) identifying the major feedbacks and interactions between climate, socioeconomic, and ecological influences on changes in land use and land management, c) determining the key sources of uncertainty and major sensitivities in projecting characteristics of land use and land cover change 5 to 50 years into the future.

Specific Research Goals

4.1. *To inventory current land use and land cover modeling methods and approaches, examining strengths and weaknesses of various modeling approaches for meeting LULCC research and assessment goals, to compare the data sets used to run these models and develop methods for determining current model uncertainty and skill. (2 years, Priority1)*

This is seen as a first step towards harnessing existing models and knowledge gained from these models, to produce state-of-the-science assessments that match the needs of the CCSP, to refine model data requirements and to advance model capabilities and evaluation methods. It will be productive to identify a common framework for evaluating modeling approaches for projecting land cover and land use changes at different spatial and temporal scales. This will require an initial review of existing models followed by a series of model intercomparison workshops examining model performance. This task is proposed as an Initial Integrative Pilot Project (see Section 7)

4.2 *To develop and apply single-sector (e.g. for urban, agriculture, forest etc.) and combined multi-sector change predictive models, incorporating advances in our understanding of drivers to meet specific CCSP and CCRI objectives. (Ongoing, Priority 2).*

Existing models of land use and land cover change within various sectors will serve some of the purposes for which land use and land cover change projections are required. There is a need for these models to be dynamic, incorporating the processes of land use and land cover change and to be available at a range of time and space scales. Where these models are intended to inform management or decision making, they should be developed and tested in conjunction with the intended stakeholder communities. In some cases linkages and feedback may be needed with models from other elements of the CCSP. Research is also needed to develop models that fill gaps in the set of existing of models available.

4.3 *Development of a Community Land Use and Land Cover Change Model (CLUCM) (3 years – Priority 1)*

An important element of this science strategy is the development of a Community Land Use and Land Cover Change Model (CLUCM) to couple to the Community Climate Model. This model would most likely require integration of components from existing models and would be very coarse spatially by the standards of existing land use and land cover models, roughly 10-20 km. The outputs of the model would be land surface characteristics that affect processes in the climate models (e.g., albedo, surface roughness, etc.), but these need to be modeled as outcomes of land use (e.g., urbanization) and land cover (e.g., disturbance) change processes. The Community Land use and Land Cover Change Model might be a simple distillation of dynamics identified in more spatially and temporally detailed local, regional and national models. Because a CLUCM would likely rely on climate inputs and produce outputs that affect climate, joint research efforts with climate-change modelers are need to identify appropriate points of interaction and spatial and temporal scales.

Timeline and Costs

Total cost to realize this research strategy focused on projecting land use and land cover change is $40 million over the first 5 years, or an average of about $7 million per year in the first five years. Funding requirements in years 6-10 will be reduced to $1 million per year to cover model refinement, as projections are increasingly integrated with other elements of the land use and land cover change science program.

CHAPTER 5: INTERACTIONS OF LAND USE AND LAND COVER CHANGE WITH CLIMATE VARIABILITY AND CHANGE

Introduction

Land use and land cover change are linked in complex ways to global climate change, and the feedback between the two exists at multiple spatial and temporal scales. Land use and land cover affect climate through changes in greenhouse gas emissions, albedo and surface roughness, while climate variability and change, in turn, can affect the ways in which land is used and the land cover of a given area. Research is needed to improve knowledge and understanding of how climate variability and change affect land use and land cover, and to identify potential feedbacks of changes in land use and land cover to climate. Research is also needed to identify past changes in land use and land cover that are attributable to changes in climate in order to project future changes in land use and land cover that could result from changes in climate. There are three strategic steps needed to answer the overarching question of interrelationships between climate variability and change and land use and land cover, identified in Chapter 6.

Specific Research Goals

5.1 Assess the current state of scientific understanding and research needed to meet stakeholder needs on the climate and land use and to focus this research on national and regional climate change (Ongoing – Priority 2).

There is considerable interest to understand the vulnerability of land use and land cover to climate variability, including the impact of potential extreme events and change, for example the impact of long term drought on land use and the associated physical and socioeconomic conditions warrants attention. Further study is needed to better understand how land surface changes force weather, climate variation, and climate change. There is also interest in better quantifying how climate variability and change affect land use and land cover change with respect to global carbon and nitrogen dynamics.

5.2 Conduct sensitivity studies to determine the atmosphere response to forcing from land cover variables and to identify resulting feedbacks to the land surface from the atmosphere at climatological time scales and at spatial scales ranging from local to global. (Ongoing, 4 years – Priority 2)

This requires an assessment to detect scientific gaps in previous sensitivity studies and to identify stakeholder needs. This assessment should include the development of a common data-model framework and experimental design for future sensitivity studies [less than 2 years]. Sensitivity studies of natural factors (e.g., storms, herbivory, and fire) and anthropogenic factors (e.g., cultivation, fossil emissions, and infrastructure development) are needed to improve our understanding of the contributions of the various land-surface processes (e.g., energy, albedo, greenhouse gases, and aerosols) to atmospheric forcing [4 years].

5.3 Understand the integrated interactions, including feedbacks, between land use/land cover and the atmosphere [Years 3 – 6, Priority 2].

This understanding must have a basis in long-term observations and ongoing model development. .It requires new dynamic models developed specifically to capture the feedback between land use and the atmosphere. Partnerships will be needed with other elements of the CCSP.

Timeline and costs

Total cost to realize this research strategy focused on interactions of land use and land cover change with climate variability and change is $40M, or an average of $4M per year.

CHAPTER 6: CONSEQUENCES OF LAND USE AND LAND COVER CHANGE

Research has shown clear evidence that changes in land use and land cover have significant impacts on a variety of environmental, ecological, economic and social conditions and processes. These consequences of change are both direct and indirect, and also are manifest at a range of spatial and temporal scales. Improving understanding and knowledge of consequences of land use and land cover change is an important goal of the science strategy for land use and land cover change research.

Research on the impacts and consequences of land use and land cover change will need to be directly related to, and integrated with, each of the other research themes of LULCC. Linking consequences of change to drivers of change is an important research goal for this program. Although much understanding and knowledge of consequences will be based on research developed within single disciplines, developing an integrated understanding of consequences of change to support global change research as well as land management and policy decision-making requires that the scientific program of research on consequences adopt an interdisciplinary approach. The research should aim to develop quantitative metrics of impacts to provide objective information to support management and policy decision-making. The critical requirement for integrating research and management is development of active collaboration and partnership between scientists and stakeholders. Adaptive management provides one framework within which this collaboration and understanding can develop.

Research is needed to develop and extend a robust, comprehensive, and scientifically defensible framework for organizing and prioritizing research to provide a holistic evaluation of consequences of change. Such a framework will provide a mechanism for organizing relevant research, enable managers easily to see research gaps and help to establish research to address priority topics. The framework will also provide a way to look at priorities among different types of land use and land cover changes. Developing this framework can be achieved through a series of impacts workshops and white papers.

Research needs for consequences of land use and land cover change are examined in selected categories of consequence e.g. Human Health, Managed and "Natural" Ecosystems and Water Quality. These topics are neither exclusive, nor do they identify an exhaustive set of issues. For the impacts addressed, products will provide valuable information about possible scenarios of land use change that will be of use in decision-making and resource management; the research will also link directly with the Decision Support Resources Development objective of the US Global Change Strategic Plan.

Specific Research Goals

6.1 Conduct a series of workshops to synthesize current knowledge and develop research agenda on land use and human health (Ongoing, Priority 2).

Workshops are proposed on LULCC and urban air quality and LULCC and contagious and vector-borne diseases. These workshops would generate review and synthesis reports and define a community research agenda, providing input to subsequent agency calls for proposals in these areas. The former workshop would lead to research that will develop risk assessment models to evaluate the human health cost of changes in air quality. The latter workshop would involve epidemiologists, biomedical statisticians and land use scientists. The workshop will lead to research that develops risk and exposure models for use in projecting consequences of land use and land cover

6.2. Conduct research to better understand LULCC impacts on food security and societal vulnerability (Ongoing, Priority 2).

Research is needed to develop a scientific understanding of the relationship between land use and land cover change and local and regional food security, land degradation, economics and human well being. This goal would also examine societal vulnerability and the potential impacts of land use on floods and drought on food security. This would build on the modeling initiatives developed in 5.1 above.

6.3 Develop monitoring techniques and strategies to understand the consequences of LULCC on changes in surface and subsurface water quality and quantity).

A workshop is needed to inventory the state of knowledge for monitoring techniques and strategies that identify the status and changes in surface and subsurface water quality and quantity and the relationship with patterns of land use and land cover at local, regional,

national and global scales. The workshop would lead to research on models relating surface and subsurface water quality and quantity to specific land cover and land use patterns and changes. This workshop would be held in conjunction with the CCSP Water Cycle element. .

6.4 Assess the impact of LULCC on Carbon Cycle and managed and natural ecosystems (Ongoing, Priority 1).

A research program is needed to evaluate the rates and consequences of conversion of natural and managed ecosystems into urban and other land uses and the impact on the Carbon Cycle. This research will focus on the spatial influence of land use changes that are projected into neighboring areas. This is an important spatial characteristic of certain land use changes for which change in and near natural ecosystems provides an exemplary case study. The research will also allow detailed quantification of the impacts of change in ecosystem services over the recent past and present in both managed and natural ecosystems, and develop models that allow projection of the ecological consequences of land use and land cover change into the future. The task will include studies on the impacts of urban and agricultural extensification and intensification over a range of scales. In addition to addressing ecosystem goods and services, particular attention will also be given to the impacts of LULCC on the carbon cycle. In the early stages of the program workshops will be held in the framework of the Carbon Cycle and North American Carbon Project. These studies will be undertaken with the Carbon and Ecosystem elements of the CCSP.

6.5 *To increase knowledge and understanding of land management decisions in moderating the possible effects of land use and other global changes (Ongoing, Priority 2).*

Research is needed to increase knowledge and understanding of land management decisions in moderating the possible adverse effects of land use and other global changes. Research will focus on case studies of adaptive management and best management practices in different land use and land cover types among a broad range of land management stakeholders. The products will be decision models of land management decision-making behavior and improved understanding of how scientific information is used in decision-making and land management.

Timeline and Costs

Total cost to realize this research strategy focused on consequences of land use and land cover change is $30 million over ten years, or an average of about $3 million per year. The five proposed impacts workshops targeted at bringing together scientists and stakeholder communities would have an estimated cost of $100,000 each, including cost of publication and wide dissemination of the workshop products.

7. STRATEGIC CONSIDERATIONS FOR IMPLEMENTATION OF THE RESEARCH PROGRAM

The research community recognizes that how the program is implemented will have implications both for the research that is undertaken and for the overall success of the program.

Interagency Coordination

The science community recognizes the importance of a coordination mechanism to develop a more holistic approach to land use research. A coordinated program should give balance to the various components of the research program encouraging different agencies to support those aspects of the research that fall within their mandate. To facilitate coordination, it is recommended that a point of contact for land use research be developed within each of the agencies that participate in the LUIWG and that each of the agencies develop one or more research focus areas around their contribution to the CCSP land use element goals. From the priority research areas identified above it is clear that NSF has a critical role to play in this interagency program, strengthening the exploratory aspects of land use science, supporting the social science aspects of the program and the associated survey data collection and strengthening the model development activities.

It is recommended that the LUIWG establish a Program Officer to facilitate the interagency coordination, help engage additional federal agencies within the program and facilitate coordination between the land use element and other elements of CCSP. The Program Officer would also help strengthen involvement of the stakeholder community in the program and help with broad program outreach to the public.

LULCC Steering Group

It is recommended that a Science Steering Committee be established consisting of leaders in the field and representative stakeholders. Amongst other tasks this group would support and advise the program on scientific issues as related to the LULCC science questions, priorities, needed experiments, measurements and observations and would undertake an annual review of progress of the program and the agency contributions with respect to meeting program goals and deliverables.

Strategic Components

Stakeholders: Stakeholders will be integral to supporting and developing the research, and will play an important role in helping to develop additional programmatic components. It is necessary that stakeholders be identified and involved in developing the program. Agencies need to develop a strategy for stakeholder participation, and agencies and scientists should ensure that stakeholders are full participants on teams conducting research focused on the goals and objectives described in this Science Strategy.

Observations: The LUIWG and LSG will need to play a proactive role in ensuring that the infrastructure is put in place to provide the satellite and in-situ observations needed for LULCC research. The science requirements will need to be fully developed and included in the priorities for the CCSP Observation Group. Particular, attention will need to be given to ground-based and socioeconomic observations and international

coordination of the required global observations. A data policy allowing free and open data exchange will be critical to the success of the science program. Opportunities should be sought for securing the necessary LULCC observations in the framework of broader programs, for example LULCC observations have a central role to play in the emerging strategy of the Group on Earth Observations (GEO).

Computing Infrastructure: The program described in this document requires the provision and management of large volume high spatial resolution data and computer intensive models. An initiative is needed to ensure that there is sufficient computing capacity and infrastructure within the research community to analyze and share large volumes of data and to run models at the spatial and temporal resolutions needed to capture land use and land cover changes and processes.

Education: There is a need for investment by the program in basic education to ensure there are sufficient scientists coming into the program during the next ten years that understand land use science and have the necessary skills to undertake interdisciplinary research combining social and physical science. A strategy needs to be developed early in the program to strengthen this underpinning to the research encouraging land use education at undergraduate and graduate levels.

International Cooperation and Coordination: Additional progress in the near-term will be achieved by participation in International research programs focused on land use and land cover change, such as the international Land Use and Land Cover Change (LUCC), LAND and iLEAPS programs, The Global Terrestrial Observing Sysytem (GTOS) Global Observation of Forest Cover / Global Observation of Land Cover Dynamics (GOFC/GOLD) program and the emerging Integrated Global Observations of Land (IGOL) program will be important mechanisms for international observation and coordination for land cover. Regional science initiatives such as North American Carbon and Northern Eurasia Earth Science Partnership Initiative will have strong land use/land cover components. Many US scientists are already active in these and related programs and greater involvement of stakeholders and agencies would be beneficial.

CCSP Inter-Element Coordination: The need for strong linkages between the Land Use and Land Cover element and the other CCSP elements is recognized. A series of joint workshops should be held early in the program to develop the interface between these elements and to determine the product requirements. Development of a Community Land Use and Land Cover Change Model will be a critical component and will not only cut across the different elements of the Land Use and Land Cover science strategy, but will link with many other elements of the CCSP.

Suggested Near- term Priority Activities

Within the next 12 months, the highest priority should be given to three, early Integrative Interagency Pilot Projects (IIPP). These strategic projects should be developed jointly between the agencies to demonstrate that the agencies can work together effectively, and to provide a contribution to the CCSP Assessments and Synthesis products. The IIPP would help the agencies focus on some of the generic obstacles to progress, such as how

to develop multi-agency support, data sets and access and consensus models. Examples of such IIPP initiatives include

IIPP 1. Land Use and Carbon. (in partnership with the CCSP Carbon WG). Coordination workshops should be held within the first two years i) building on the Land Use and the North American Carbon Project, ii) examining the impact Land Use history and recent and current impacts of land use change on the global carbon cycle, iii) the projection of future US land use on the carbon budget.

IIPP 2. A National Research Council/National Academy of Sciences-sponsored review of land use models, best practices, scientific readiness, obstacles, and agency roles would be extremely helpful to the land use and land cover change program and would help the agencies identify ways to strengthen this crucial part of the research agenda. Funding should be sought from participating agencies to enable this review to take place as soon as possible.

IIPP 3. The development of a Community Land Use and Land Cover Change Model (CLUCM) identifying the land use and land cover equivalent of the two times CO_2 scenarios (See 4.3). The model would draw on elements from all the research goals presented in Chapters 2-6, and would also provide a test bed for interagency cooperation. The model would be a community effort involving scientists, stakeholders, agencies, and the science steering committee, as well as participants from other elements of the CCSP. The goal of the CLUCM and the model development process would be for the land use community to synthesize its knowledge and understanding to develop a land use model that both projects land use into the future and is capable of linkage with other elements of the CCSP.

IIPP Timelines and Costs

The pilot projects are part of the overall research agenda and should be initiated immediately and completed as soon as possible. The cross element workshops with the Carbon group would cost c. 50K each, including the publication of the meeting reports and associated white papers. The costs of the NRC sponsored study are to be determined but could cost c.100-200K. The costs of the community model would include two or three workshops and funding for modeling group participation and common data set generation over a 3 year period. Estimated costs for 3 years would be c.$1.7M. Total costs over 3 years for the three IIPP's would be c. $2 M

Table 1. Summary of Tasks and Estimated 10 year Program Costs.

Task	Interagency Integrative Pilot Projects	Schedule / Priority	Est.10 yr Cost
IIPP 1	Land Use and Carbon - Cross Element Workshops	Immediate / Immediate	
IIPP 2	NRC Sponsored Model Review	Immediate / Immediate	

IIPP 3	Community Land Use Model Development	Immediate 3 yrs / Immediate	
			$ 2 M *
2	**Characterizing Historic and Current LULCC**		
2.1	Improving specification of data requirements	2 yrs / Priority 1	
2.5	Standardized data sets and models	6 yrs / Priority 1	
2.3	Enhance ground-based observations	Ongoing / Priority 2	
2.4	Improve access to land use data	Ongoing / Priority 2	
2.6	Education and Training of LU scientists	Ongoing / Priority 2	
2.7	Historical LULC data acquisition and access	6 yrs / Priority 2	
			$40 M
3.	**Understanding the Causes of LULCC**		
3.1	Causes and Projections of Change and potential interventions	Ongoing / Priority 1 / 2 yrs initial synthesis	
3.2	Improving feedback between data, analysis and modeling	Ongoing / Priority 2 / 2yrs for initial workshops	
3.3	Understanding of drivers and policies	Ongoing / Priority 2 / 2 yrs initial assessment	
			$12.5 M
4	**Projecting future LULCC**		
4.1	Inventory modeling methods (see IIPP2)	2 yrs / Priority 1	
4.2	Develop predictive models	Ongoing / Priority 2	
4.3	Develop the CLUC Model (see IIPP3)	5 yrs / Priority 1	
			$40 M
5	**LULCC and Climate Interactions**		
5.1	Assess and implement stakeholder oriented LU/Climate research	Ongoing / Priority 2	
5.2	LU forcing and feedbacks on climate	Ongoing / Priority 2	
5.3	Integrated interactions	Yrs 3-6 / Priority 2	
			$40 M
6	**Consequences of LCLUC**		
6.1	Research and workshops on LULCC and human health	Ongoing / Priority 2	
6.2	Research on LULCC on food security and human vulnerability	Ongoing / Priority 2 / initial workshop year 2	
6.3	Monitoring and analysis of LULCC and water quality and quantity	Ongoing / Priority 2 / initial workshop year 2	
6.4	LULCC, Carbon Cycle and Ecosystems (see IIPP 1)	Ongoing / Priority 1	
6.5	Land Management decision-making	Ongoing / Priority 2	
			$30 M

	Est. Total Program Cost over 10 years		$162.5 M

* The estimated total cost of the IIPP's is given but it should be noted that these costs are included in the task totals below.