**USGS EROS Center Science Strategy**
**October 8, 2015**

## 1.0 Introduction

The Earth Resources Observation and Science (EROS) Center science and applications mission has evolved since the doors opened in the early 1970's. Science and applications has been a core EROS activity from the beginning, but the role of science and applications in meeting the EROS, U.S. Geological Survey (USGS), and the Department of the Interior (DOI) mission has evolved over the past 42 years. There were periods in this evolution in which science priorities were stable but incremental advances in technology and staff capabilities along with programmatic shifts pushed the program into new areas and to higher levels. There was a period of revolution when the science and applications mission made significant adjustments to meet new priorities associated with the establishment of the U.S. Global Change Research Program (USGCRP) by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act (GCRA) of 1990. The GCRA purpose was to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." The GCRA and USGCRP triggered a revolution in EROS science and applications priorities and EROS science transformed from a series of localized remote sensing and geospatial data applications to the current emphasis on large-area mapping and monitoring.

Since then, EROS science and applications have evolved gradually due to programmatic factors (i.e., changes in organizational alignment, new EROS management practices, adjustments to funding sources, etc.) but the EROS science and applications program has not experienced a second revolution. This is somewhat surprising considering that over the past 7 years, the EROS Center was the catalyst for a revolution in Landsat science and applications due to the Landsat free data policy and the amazing growth in the depth of the historical Landsat archive. In addition, during this period societally relevant issues associated with climate change, population growth, water supply, natural resources management, public health, and other forces have upped the ante for a new revolution in EROS science and applications. Managing the consequences of a changing world requires a more aggressive and focused approach than ever before. It is time for a second revolution that shapes the EROS Center science and applications program as major contributor to the understanding our changing Nation and Earth.

### 1.1 Current Situation

The USGS EROS Center mission is focused on "…contributing to the understanding of a changing Earth through research to operations activities that include developing, implementing, and operating remote sensing based terrestrial monitoring capabilities needed to address science and applications objectives at all levels – within the USGS, across the Federal government, and around the world." This mission vision translates into three primary goals (Kelly, 2015):

1. Serve as the world's primary source for land remotely sensed images of the Earth.

2. Be authoritative providers of land change science data, information, and knowledge.

3. Serve as leaders in understanding how changes in land use, cover, and condition affect people and nature.

The three EROS Center goals specify the EROS science and applications mission – land change science.

### 1.1.1 Land Change Science – What and Why?

Land change science, defined initially by Rindfuss et al. (2004) and expanded by Turner III et al. (2007), has emerged as the foundation for understanding global environment change and sustainable resource management.

> *Land change science seeks to understand the interactions between people and nature that lead to changes in the type, magnitude, condition, and location of land use and cover. The land change science agenda addresses dynamic coupled human-environment systems through an understanding of concepts and theories, and the use of remote sensing, modeling, and synthesis to understand and explain land change rates, causes, and consequences.*

Changes in land use, land cover, and land condition, have positive and negative affects on people and natural systems. These changes are the result of human activity (e.g., land use changes motivated by economic drivers or public policy) and natural phenomena (e.g., weather and climate variability, geologic events). Regardless of the cause of change, there are positive benefits such as increasing wealth in communities and protecting natural areas. However, there are also negative impacts that must be identified, understood, and managed in order to mitigate adverse impacts on weather and climate, water quality and quantity, habitat and biodiversity, and public health and well-being.

The importance for understanding land change is well known. In 2001, the National Research Council (NRC) identified land change (specifically land use and land cover) dynamics as one of seven 21st century grand challenges in the environmental sciences (NRC 2001). The NRC study concluded that an improved understanding of land change dynamics is essential for managing the impacts of land change on human and natural systems, including contributions to anthropogenic releases of $CO_2$ to the atmosphere, changes in hydrologic dynamics and nitrogen cycling, modifications of terrestrial habitat, disruptions of species migration, and role in the spread of disease vectors.

The EROS Center has deep roots in land change science due to its historical affiliation with the USGS Geography Discipline. The 2005-2015 USGS Geography Strategic Plan (McMahon et al. 2005) recommended a formal land change science agenda, and several subsequent internal USGS studies, including the Geography Science Synthesis Team (Loveland et al.

2010) and the recent USGS Climate and Land Use Change science strategy (Burkett et al. 2011) endorsed coupling climate and land use and land cover to understand global environmental change. These documents clearly infer that EROS expand and improve the use remote sensing for understanding land and water characteristics and dynamics.

### 1.2 Setting the Stage for the Future

The core of the EROS science and applications agenda is land change science, as articulated in the Land Change Monitoring, Assessment, and Projection (LCMAP) vision. LCMAP is the EROS foundation for land change science as it represents the framework for:

> *An interdisciplinary science and applications program that generates and uses land change data and information products to explain how the patterns, processes, and consequences of changes in land use, land cover, and land condition, at multiple spatial and temporal scales, affect people and nature. LCMAP provides a capability to continuously track and characterize changes in land cover, use, and condition and translates this information into assessments of current and historical processes of change in order to support evaluations and decisions relevant to environmental management and policy.*

As a federal science agency research center, EROS staff has a responsibility to focus science and applications activities on areas where there is a recognized problem affecting society. The US faces many societal grand challenges affecting economic, environmental, and homeland security, including climate change and sustainable natural resource management. Federal researchers provide the objective data, information, and assessments required for understanding and managing these societal grand challenges. To be relevant, we must focus on critical societal issues where EROS can contribute critical answers or solutions. In her 2015 state of the USGS address, Acting Director Suzette Kimball said "the idea is to challenge ourselves to focus on and pursue issues and questions that matter or will soon matter to our Nation and world." This translates into a science agenda that is forward looking and relevant to the needs of the Nation. Land change science and applications, focused on those grand challenges is an area where the staff at the EROS Center are uniquely poised to contribute. The challenge we face at EROS in establishing science priorities for the coming years is defining a uniquely federal high priority niche that is aligned with our capabilities and not redundant with other centers.

Focusing a forward-looking agenda on national needs requires understanding current federal priorities as well as emerging issues. Clearly, topics relevant to DOI and the USGS are a priority, but issues related to the needs of other Federal agencies and our long-standing EROS legacy obligations are also important. Regarding the latter, the EROS stewardship of the Landsat record brings unique responsibilities that need to be woven into our long-term science plans.

### 1.2.1 Landsat Stewardship

The EROS Center has a special responsibility as the steward of the unprecedented Landsat record. In fact, the establishment of the EROS science and applications program was driven by the need to add value to the newly established global Landsat record.

The Landsat mission was established to map and monitor land use and land cover and to distinguish between human and anthropogenic change, and "as the longest-running continuous satellite image dataset for land processes, Landsat data provide unparalleled witness to the enormous changes occurring on Earth since 1972" (Kennedy et al. 2014). The importance of Landsat for understanding land change was identified in the U.S. Climate Change Science Program's (CCSP) science strategy (CCSP 2003):

> *"One of the great challenges is how to relate human incentives, behavior and action at particular localities to land cover change at broader (e.g., regional) geographic regions. The fine spatial resolution of Landsat images along with its global geographic extent provides the necessary data for making this linkage."*

The Landsat record was historically underutilized, but now, due to the convergence of science, technology, and public policy (e.g., free access to Landsat data), the systematic land change information envisioned by the Landsat founders can now be produced that are:

- Continuous since 1972 and extended indefinitely into the future
- Updated shortly after change occurs
- Global in extent
- Comprehensive in the provision of information on land use, cover and condition attributes and trends.

With more than 5.8 million Landsat images in the USGS archive and as many as 1200 new images being added daily, this massive archive is ripe for exploitation and a central element of an EROS capability to contribute to understanding past and present land use, land cover, and land condition changes needed in a land change science program.

### 1.2.2 DOI Strategic Plan

The current US Department of the Interior strategic plan emphasizes the need to contribute to the quality of life for US citizens and communities, and to advance stewardship goals and energy independence (DOI 2014). The plan stresses the need for world-class science that contributes to protecting the public from hazards and providing critical information on the earth, energy, water, and resource conservation. Most DOI goals are based on a landscape perspective, such as *Powering Our Future and Responsible Use of Our Resources*, *Ensuring Healthy Watersheds and Sustainable, Secure Water Supplies*, and *Building a Landscape-Level Understanding of Our Resources.* The latter is particularly consistent with the EROS mission due to goals to provide applied and basic scientific

research and the development of "science products to inform decision making by DOI's bureaus and offices and local, state, national, and international communities." This goal specifically calls for the use of Landsat data and science focused on generating land cover, natural resources management, and biological carbon sequestration products.

### 1.2.3 USGS Science Strategy

The USGS EROS land change science emphasis couples seamlessly with the broad 2007-2017 USGS science goals that focus on societal issues (e.g., ecosystem status, climate variability and change, energy and minerals, national hazards, water security, and the environment and human health (USGS 2007). All of these issues are major national challenges relevant to the DOI mission. A further clarification of the science needs for these broad goals are found in a series of individual science strategies. For example, the USGS climate and land use change science strategy (Burkett et al. 2013) provides clear guidance for USGS climate and land use change research, but also considers the broader global environmental change priorities that span the USGS. This strategy identifies seven specific goals. The fourth goal, addressing land-use and land-cover change rates, causes, and consequences, is quite consistent with the EROS mission, and it connects directly to several other climate and land use goals, including the global carbon cycle, biogeochemical cycles and their coupled interactions, droughts, floods, and water availability under changing land-use and climatic conditions, biological responses to global change, and coastal response to sea-level rise, climatic change, and human development.

Two priorities in the USGS climate and land use change science strategy stand out as being closely connected to EROS land change science capabilities. As mentioned, the fourth goal, improving understanding of land-use and land-cover change rates – rates, causes, and consequences is directly aligned. This goal sets the vision to "explain how changes in land use, cover, condition, and land management alter climate, impact natural systems, and affect human health and well-being." To do this, the following critical elements require investigation:

- Monitoring patterns of land change, including disturbances, using ground surveys and long-term, high-quality geospatial data from calibrated and validated remotely sensed imagery.
- Identifying drivers of change and applying spatially and temporally explicit models to forecast plausible scenarios of land change.
- Assessing consequences of past, present, and future land change on vulnerability and resilience of coupled human-environment systems and the services they provide.
- Applying land-change science and knowledge to policy and decision making to address consequences of land change and inform critical DOI issues.

The second EROS-relevant activity from the climate and land use change science strategy deals with monitoring. Specifically, there is a need to "develop calibrated and validated

geophysical measurements and integrated data products with the accuracy and precision needed to map, measure, and monitor land changes attributed to climate change, other natural disturbances, and human activity; and identify and evaluate new remote sensing technologies to provide measurements needed to detect and monitor global change." As the USGS center responsible for providing synoptic Earth observations, this monitoring emphasis is clearly our priority.

The EROS science and applications staff are also involved in activities with other USGS missions, such as Core Science Systems, Water, and Natural Hazards. Clearly, EROS remote sensing and geospatial data handling and analysis capabilities are relevant to missions and programs across the USGS and our interaction with them should be carefully expanded.

### 1.2.4 Other Federal Agencies and Initiatives

The EROS Center has had many collaborative relationships with federal agencies and activities since its inception. The number and duration of our collaborative activities are too large to itemize. However, it is important to note that our long-standing relationship with NASA involving Landsat and the Earth Observing System (EOS) continues and we have shared science and applications objectives. The EROS fire science activity is based on excellent relationships with DOI bureaus and the U.S. Forest Service. The EROS Center has contributed to U.S. Agency for International Development (USAID) objectives for more than 20 years and USAID is a key partner in their food security and climate impacts mitigation mission.

In addition to bilateral agency cooperative investigations, we also play a role in interagency ventures. For example, our land cover partnerships that were established through the Multi-Resolution Land Characterization (MRLC) consortium have provided major benefits and will continue to be important to our land change science activities. As a member of the U.S. Global Change Research Program (USGCRP), we are also obligated to contribute to relevant federal climate change initiatives. For example, EROS staff have played leadership roles in the USGCRP National Climate Assessment and contributed research on climate and land use issues. The most recent National Climate Assessment identified the importance of an ongoing climate and land use assessment capability and this has led to the establishment of National Climate Assessment indicators and indicator teams (Melillo et al., 2014). EROS staff are currently contributing to the planning of the indicators activity and could be an important contributor to both the assessment capability and the operational indicators effort.

Every administration brings specific science priorities that shape our mission. The President's Climate Action Plan is an example, and is founded on the simple, direct premise that "steady, responsible action to cut carbon pollution" will slow the effects of climate change and reduce the adverse impacts on people and natural systems. One of the actions in the President's plan is to increase the understanding of climate change impacts by improving the information and tools needed by decision makers to respond to weather and

climate variability and change. This is an example of a societally relevant priority that could shape our science and applications program.

The list of opportunities for research in support of DOI, USGS, and other federal agency priorities is almost endless. While we clearly have an obligation to contribute, we in fact, have a finite capacity and need to think strategically when determining what issues and the level of involvement are most appropriate for EROS. We will need discipline to stay on mission. Part of the needed discipline is to adhere to a set of guiding principles.

## 2.0 EROS Center Science and Applications Guiding Principles

At the highest level, the EROS science and applications program strives to be relevant, have an impact, exhibit national and international leadership, and to advance innovation. To shape the process of winnowing opportunities into a relevant science and applications agenda, the following guiding principles should be considered:

- The most recent USGS science strategy documents (circa-2013) set the initial boundaries for our science priorities. The climate and land use change science strategy is especially important for shaping our science agenda (Burkett et al., 2013).
- Our science and applications projects should use EROS mission relevance as the highest priority.
- All science and applications projects must align with the EROS mission and improve the value of EROS land remote sensing assets and land change science priorities.
- Contributing to LCMAP goals and philosophy is required since LCMAP represents the foundation for transformative, integrated, and focused science and applications.
- EROS science focuses on large-area (e.g., regional, national, global scale) land change topics and processes.
- We are fundamentally an applied sciences group, with strong roots in developing the basis for ongoing land characterization.
- EROS projects should span the continuum of land change science elements – remote sensing and monitoring, assessment through modeling and synthesis, and modeling and projections to understand future states and their consequences.
- We should consciously transition from being a data and information producer to becoming more invested in land change assessment and projection.
- Case studies, or assessments, are important as long as they are tied to important scientific or societal issues.
- Our ultimate challenge is to simplify the complex by using assessments and synthesis capabilities to translate phenomena and interactions complexities into understandable knowledge.
- The elements of the EROS science agenda must be unique and relevant rather than one that can be done by universities, private consultants, or other Federal Agencies. We should seek to strengthen our capabilities through partnerships and collaboration.

- We should strive for a smaller number of larger, high-impact projects, and we should deliberately identify synergy between projects. We must reduce the number of one-off individual-driven studies.
- Reimbursable income is important but it should not drive the types of work we take on. Instead, reimbursable activities should be pursued that augment our core science priorities and permit extension into new areas or the strengthening of current activities.
- Pursuit of high-risk research is acceptable if the potential gains are important to the long-term success of the EROS science and applications program. A strong external peer review process can help navigate the balance between relevance and risk.
- Innovation should be pursued whenever possible. Our emphasis on innovation should be driven by people's creative ideas and theories and supported by the teams that have the capabilities and authority to implement them.

EROS science and applications activities should meet the intent implied in these principles. Rationalizing projects with creative interpretation of these principles will not allow EROS to elevate science and applications investigations to provide the "definitive land change information and knowledge for the Nation and the globe" that is clearly expressed in the EROS mission goals. However, perfect adherence to these principles is unlikely not appropriate since tangential activities are often called for due to EROS and USGS priorities. Tangents, however, should be undertaken with caution.

## 3.0 The EROS Center Science and Applications Science Agenda

The EROS science and applications agenda is focused on land change science, and Landsat and land remote sensing is central to land change science. The previously mentioned LCMAP foundation establishes the framework for addressing the EROS science and applications goals and illuminates the path for the provision of definitive land change information and knowledge. The intended LCMAP philosophy is to transform EROS science and applications from being data centric to a program that includes a greater emphasis on the provision of land change knowledge, e.g., what are the characteristics of land change and how is change affecting people and natural systems. It is the structure for our science and applications and LCMAP's focus is a set of priority topical goals.

### 3.1 EROS Science Goals

With LCMAP as the structure for organizing, producing, and delivering land change science products, its viability depends on a relevant science and applications agenda that includes topical science goals that are the basis for our specific projects and activities. The three science goals associated with our land change science priorities and LCMAP include:

1. Improving global land change monitoring through remote sensing research.

2. Understanding the temporal and geographic dimensions of land change.

3. Improving the understanding of the connections between climate and land change (e.g., land use, cover, and condition) and their combined impacts on human and natural systems.

These three goals represent the topical scope of our science and applications priorities. Each goal is described in more detail in the following sections.

### 3.1.1 Improving Global Land Change Monitoring Through Remote Sensing Research

As one of the world's largest remote sensing centers, EROS must maintain strong, relevant remote sensing science capabilities. Those capabilities should be particularly strong in areas that relate to our land change science mission, our Landsat stewardship role, and our land remote sensing archive responsibilities. Remote sensing research in support of the land change science mission should focus on:

- Enhancing the detection of land use, cover, and condition change.
- Defining the scales, precision, and accuracy of data needed to detect land change.
- Improving the timeliness and reliability of land cover and land condition monitoring systems.
- Identifying new standards and observations needed to detect, attribute, and manage land change consequences.
- Integrating *in situ* and remotely sensed observations.
- Systems and algorithms for generating calibrated and validated geophysical measurements and data products suited to the detecting and monitoring global land changes.
- Calibration, cross-calibration, and validation of the radiometric and geometric characteristics of EROS land remote sensing observations.

We must maintain a strong workforce that focuses on improved radiometric and geometric consistency across measurement systems, and includes the expertise to troubleshoot issues associated with all phases of the Landsat record. In addition, we need to have a broad-based perspective that permits intelligent prioritization and evaluation of potential new remotely sensed measurements, informed by how these instruments can effectively be used to retrieve the geophysical and biophysical parameters required for monitoring and understanding terrestrial systems.

### 3.1.2 Understanding the Temporal and Geographic Dimensions of Land Change

This goal calls for generating the geospatial and statistical data and information and conducting the analyses that are needed to explain basic land use, cover, and condition

topics. Specifically, EROS should produce data and information that leads to a clear understanding of:

- The rates and drivers of contemporary land use and land cover change.
- Land use, cover, and condition variables that have the greatest impacts on, and that can be used to characterize the resiliency of, human and natural systems.
- Identifying geographic regions and land use and land cover types that are most and least vulnerable or resistant to climate change.
- Land use practices that either enhance or decrease the effects of climate change on people and natural systems.
- The rates and patterns of future land use and land cover change.

Even though there are significant operational mapping and characterization activities associated with this goal, the synthesis of those data is a basic research activity and the results and will lead to clear advances in our understanding of the nature of land change. To best achieve success, this goal will require advances in mapping, monitoring, and synthesis. Improving our understanding of the basic geography of land use and cover and our statistical characterization capabilities will be needed to develop the required results.

### 3.1.3 Improving the Understanding of the Connections Between Climate and Land Change and their Combined Impacts

The USGS is committed to research that addresses how land change and climate together affect environmental systems. This requires research that leads to an understanding of the role of land and climate change as both a forcing and a feedback. The USGS climate and land use science plan calls for land use and climate research connected to (Burkett et al., 2013):

- Carbon cycle and other greenhouse gases.
- Carbon sequestration in ecosystems.
- Biogeochemical cycles.
- Weather and climate.
- Water availability, water use, and water quality.
- Ecosystem services.
- Ecosystem structure and function.
- Species distributions and habitat condition, including fragmentation.
- Coastal natural systems in conjunction to sea level rise, storm impacts, and sea temperature change.
- Coastal variability, vulnerability, and resilience to sea level rise.

Our challenge is to identify a small number of high priority topics that are aligned with our capabilities. We clearly cannot take on the land change connections with all of these areas. For example, we have research underway that is addressing aspects of water availability, use, and quality, but we have a limited focus on the connection with land use. We have a

robust capability to address biogeochemical and carbon cycle issues, but we must define a unique focus that does not duplicate other USGS projects. We have a number of studies underway that address aspects of ecosystem health and functioning, but we do not have clear goals linked to USGS and DOI priorities. Any future investment in research in these areas must begin with a clear plan that identifies an appropriate science and applications niche.

Considering both EROS capabilities and research being conducted elsewhere, priorities should be given to investigations on land use connections to water, weather, climate, and coastal issues. Regarding the latter, research on land use, water, climate, and coastal impacts is a potential area for a new investigation that uses a national, synoptic perspective to understand the unique challenges facing coastal regions. While there is considerable capability within the USGS to address coastal vulnerability to storms, sea level rise, and other threats, an ongoing assessment capability using our tools and synthesis capabilities could be developed that leads to a better understanding of the complex connections between coastal communities and natural landscapes to climate change, sea-level rise, and human development.

Regarding weather, climate, and land use, there is considerable research in several agencies and academic institutions that are advancing an understanding of the interaction between land and atmosphere. One EROS role is the provision of land cover and land condition data needed to advance land-atmosphere interactions research. However, the niche that is growing in importance and not being addressed elsewhere involves the integrated assessment of the impact of weather and climate variability and change and the connections to water resources. For example, research on the short-, mid-, and long-term impacts of drought on land use and land cover is of particular importance.

These three EROS science and applications topical priorities (water, weather, climate, and coastal issues) are broad and relevant, but too broad to be implemented in entirety. They represent the rough boundaries of possible science and applications activities, but need to be narrowed into a specific set of actions and projects. Plans that lead to a set of priority projects with clear goals and objectives are needed.

### 3.2 EROS Science and Applications and LCMAP

The previously mentioned LCMAP concept establishes the structure for addressing the EROS science and applications goals and illuminates the path for the provision of definitive land change information and knowledge. The intended LCMAP philosophy is to set in place a foundation that transforms EROS science and applications from being data centric to a program that includes a greater emphasis on the provision of land change knowledge, e.g., what are the characteristics of land change and how is change affecting people and natural systems? As conceived, LCMAP included three broad components:

1. Provision of relevant, timely, and accurate data and information on land use, cover, and condition characteristics and dynamics.

The first topical science goal, improving global land change monitoring using remote sensing directly supports this LCMAP component. This involves research that leads to analysis ready Landsat data, research that improves the radiometric and geometric consistency of multi-temporal and multi-source remotely sensed imagery, the establishment of methods for improving the detection of changes in land use, cover, and condition, and aggressive strategies for the validation of results. A key new LCMAP capability is the establishment of near real-time change analysis – detecting change as it is occurring. Included in this activity is the implementation of the capability to alert relevant stakeholders (e.g., DOI resource managers) to important or emerging land change events in their region. There are significant opportunities to further exploit the LCMAP foundation of analysis ready data to improve and build upon the indicators proposed for use in the National Climate Assessment.

2. Assessments of the trends and consequences of land change needed by decision makers.

The second and third science goals, understanding the temporal and geographic dimensions of land change and improving the understanding of the connections between climate and land change and their combined impacts, support this component of LCMAP.

Regarding the two assessment-focused goals, this LCMAP element represents a conscious shift from primarily being a data provider to providing knowledge-based assessments. For example, high priority assessments associated with the science goal addressing the temporal and geographic dimensions of land change include:

- Provide documentation and understanding of historical land change and contemporary land change as it occurs. This should include provision of ongoing answers to this question - where, how, and why is land changing?

- Explain the geography of change now, and in the future. Capabilities are required to answer the question - where, how and why might land change in the future?

A small number of ongoing annual topical land change assessments – e.g., rates and characteristics of US 2015 land change and an outlook for the next 10 years, and periodic assessments on relevant land change topics – e.g., the impacts of past and future land use and land cover on coastal communities, should be defined and established. In addition, the capacity to undertake emerging issue assessments – e.g., the impacts of the 2012 drought on land use and land condition must be created. Our geographic focus should remain national to global as this is consistent with our Landsat stewardship responsibilities.

Building off these assessments are investigations improving the understanding of the connections between climate and land change and their combined impacts aimed at explaining how past, present, and future land change affects people and natural systems. Implied in this is answering the question - what are the impacts of land change locally,

regionally, and globally? Topical emphasis should include land change impacts on weather and climate, water resources, and coastal regions. The appropriate investments in assessment activities related to the carbon cycle, biogeochemistry, and ecosystem functioning must also be determined.

3. Services that support the use and understanding of land change monitoring information products.

This component is indirectly supported by all three goals, but is directly related to success of EROS and LCMAP. It implies a proactive effort to distribute and communicate the data, information, and knowledge produced by EROS staff. Ultimately, the purpose of a modernized land change detection and characterization capability is to generate and disseminate the science-quality products needed to address land change science issues. Historically, activities associated with this component have been addressed piece-meal. Some projects emphasized this while others did not. What is needed now is a cohesive approach and the involvement of all appropriate EROS projects. Tracking land cover, use and condition changes as they are occurring, providing near real-time intelligence to stakeholders on the potential threats and the management options available to mitigate adverse consequences, and assessments synthesizing the status of key land change science topics must be a top priority.

Collectively, these three LCMAP components represent an institutional approach to a more integrated and effective EROS land change science program. EROS science and applications has activities in all three areas, but the balance of our current projects focus on the first component, the provision of land change data. This is an important foundation for the EROS land change science program. However, our current projects can be better integrated and modernized into a state-of-the-art capability for producing a larger array of historical and contemporary land change variables. Documenting historical land change and detecting change as it is occurring is a particularly important goal as it provides the information needed to better understand the drivers of land change and their consequences. Implementing an EROS land change monitoring system capabilities requires the development of a clear, cohesive, integrated vision, across EROS, a carefully selected, relevant, and top quality set of products and services, and focused staff working on teams that build and operate those capabilities.

## 4.0 Connecting the Current Projects with our Strategic Agenda

Reorganization of the EROS Science and Applications Branch into coherent areas will bring improved focus on the three science goals and LCMAP. The new project focus areas will be more homogenous than the current team structure, and will result in more emphasis on innovation and impact. Moving forward, science and applications projects will be organized and lead through a proposed seven science focus areas. Each focus area will be lead by a principal investigator (PI) and comprised of government and contract staff that work together to plan and carry out project goals and objectives. The PI-led teams will

ensure that the EROS science objectives are addressed and the foundational elements of LCMAP are developed. The following is a definition of each of the seven science focus:

**Remote sensing R&D for land change**: Research addressing remote sensing data quality and consistency, algorithms and strategies for characterizing geo- and biophysical surface properties and dynamics including land change, and strategies for validation of remote sensing and environmental products.

**Land change products – NLCD**: Planning, implementation, and production of the National Land Cover Database.

**Land change products – Fire**: Planning, implementation, and production of land data sets needed to characterize vegetation related to fire fuels and fuel conditions, and the analysis and monitoring of burn severity.

**National and regional land change assessments**: Research, analysis, and synthesis of data leading to the development of assessments of the rates, causes, and consequences of land change.

**Vegetation, water and climate dynamics**: Quantification and monitoring of the impacts of weather, climate, and land use on vegetation condition and water resources.

**Coastal changes and impacts**: Regional to national assessments of the complex interactions between coastal communities and natural landscapes associated with climate change, sea-level rise, and human development.

**Early warning for food security**: Research and analysis leading to operational early warning forecasts and assessments of acute food insecurity.

The seven science focus areas collectively contribute to the three science goals. Table 1 lays out the seven areas and highlights their general relationship with the three science goals. All seven will ultimately play a role in meeting the broader EROS mission goal, *contributing to the understanding of a changing Earth*, and specifically to be *leaders in understanding how changes in land use, cover, and condition affect people and nature*.

Table 1. The relationship between science focus areas and the EROS science strategy goals.

| **Science Focus Areas** | **Science Strategy Goals** | | |
|---|---|---|---|
| | Improving Global Land Change Monitoring Through RS Research | Understanding the Temporal and Geographic Dimensions of Land Change | Improving the Understanding of the Connections Between Climate and Land Change and their Combined Impacts |
| Remote sensing R&D for Land Change | Primary | | |
| Land Change Products - Land Cover | | Primary | |
| Land Change Products - Fire | | Primary | |
| National & Regional Land Change Assessments | | Primary | Secondary |
| Vegetation, Water and Climate Dynamics | | Primary | Secondary |
| Coastal Changes and Impacts | | | Primary |
| Early Warning for Food Security | | | Primary |

The seven science focus areas also contribute to establishing the LCMAP foundation. In particularly they all address the EROS vision to be *authoritative providers of land change science, data, information, and know knowledge*. As presented in Table 2, the seven science focus areas are key to the success of LCMAP. The seven science focus areas play an especially important role in achieving the expected modernization and integration of EROS land change activities. In this case, EROS science and applications touch all three LCMAP objectives. The challenge ahead is for the seven science focus areas to work together to make LCMAP implementation successful.

Table 2. The relationship between science focus areas and LCMAP Objectives.

| Science Focus Areas | LCMAP Objectives | | |
|---|---|---|---|
| | Provision of relevant, timely, and accurate data and information on land use, cover, and condition characteristics and dynamics. | Assessments of the trends and consequences of land change needed by decision makers. | Services that support the use and understanding of land change monitoring information products. |
| Remote sensing R&D for Land Change | Primary | Secondary | Secondary |
| Land Change Products - Land Cover | Secondary | Primary | Secondary |
| Land Change Products - Fire | Secondary | Primary | Secondary |
| National & Regional Land Change Assessments | | Primary | Secondary |
| Vegetation, Water and Climate Dynamics | Secondary | Primary | Secondary |
| Coastal Changes and Impacts | Secondary | Primary | Secondary |
| Early Warning for Food Security | Secondary | Primary | Secondary |

## 5.0 Refining Our Science Culture

To be successful in addressing the topical science and applications goals and LCMAP needs, EROS science and applications must be achieve higher levels of excellence if we are going to be nationally competitive and a central contributor to the three broad EROS Center goals: (1) serving as the world's primary source for land remotely sensed images of the Earth, (2) enabling the investigation and understanding of the condition of the planet's landmasses, and (3) providing definitive land change information and knowledge for the Nation and the globe. With the EROS science and applications program taking on new priorities in a more integrated fashion, a parallel effort to strengthen the science infrastructure and culture is needed. Key tenants to an increasingly effective and impactful

science program involve increasing the level of innovation in our science and applications projects, and expanding the visibility, influence, and impacts of science staff and their products. There are eight programmatic areas in which we must make progress if we are to ensure the relevance of our work and improve innovation, visibility, and impact.

### 5.1 Updated Organization

EROS science and applications staff and projects are shifting to an organization based on major topical initiatives rather than funding sources. This is driven by the recognition that a shift to an organization driven by ideas is needed to improve our innovation, visibility, and impact. The specific details on the alignment must consider the science and applications goals in this plan.

In addition to aligning the organization around science goals and ideas, there is also a need to add additional authority to the science and application branch chief position. The past independence of teams has resulted in considerable variability in management practices, led to inconsistent use and supervision of staff, reduced or eliminated the mobility of project staff interested in new challenges, and has usurped the ability to quickly organize around emerging ideas. It has also led to communications problems and an erosion of the EROS science culture. The branch chief must have the power to ensure a common focus on the Center mission and priorities, participate in the equitable allocation of resources, and apply consistent and fair performance standards for all staff.

Finally, the new organization needs to be comprised of fewer projects that are more integrated and consolidated around the primary science and applications goals. The science and applications agenda must be more integrative between projects and there must be a focus on a smaller number of core activities that span the data-information-knowledge continuum.

### 5.2 Staff Modernization

The EROS USGS science and applications workforce is aging and due to flat or declining budgets and low turnover rates staffing has not been significantly refreshed with staff suited to our new priorities. Recent retirements have generally affected more senior members of the staff and as a result, the number of PhD's has declined. One of our highest science priorities must be the initiation of a campaign to refresh our staffing profile with new, invigorated and energized researchers with the education and skills needed to carry out the goals of this plan. The plan needs to include high but achievable standards. For example, we should strive to increase the percentage of PhD researchers from the current level of 20 percent of the science and applications workforce to at least 50 percent through a combination of new hires and educational opportunities for existing staff. There is a particular need to shift the balance to lower grade positions filled with early-career researchers. We should be more aggressive in the use of post-doc and term positions as a means of broadening our skill base. As we move forward, our senior scientists must

assume increased responsibility for mentoring and developing the younger staff. Returning to a more balance staffing profile is an urgent need.

Particular attention must be given to improving our quantitative skills associated with remote sensing and geospatial analysis, and expanding our expertise in synthesis and assessment. In addition, we must also seek staff with broad, integrative perspectives and a keen eye for identifying emerging science issues that are relevant to the EROS mission. We must recruit aggressively and nationally. The first step is to prepare and begin implementing a long-term USGS staffing plan that identifies key staff characteristics and qualifications and a recruitment strategy that ensures that those requirements are met. In addition, EROS contractor employers should be encouraged to embrace similar standards.

Every member of the science and applications staff should carefully consider their role in the organization. Each person should formally define their career goals and objectives and their anticipated path to achievement of those goals. This includes identifying personal development activities that increase their capabilities and impact.

### 5.3 Administrative Support

Associated with organizational adjustments, it is time to rethink the types and means for providing administrative support to science and applications staff. This needs to start with input from the scientific and technical staff. The goal should be to provide the necessary support needed to improve scientific and technical staff efficiency by reducing the individual administrative burdens that currently slow down daily progress. Special attention needs to be given to developing a support system that eases the challenges associated with preparing, reviewing, and submitting research proposals and the manuscript review and approval process. The latter will become an even greater challenge as new rules for documenting and releasing science data go into affect. Removing the disincentives of administrative tasks is an important step toward improving productivity and visibility.

### 5.4 Science Culture

Special attention must be given to improving the EROS science and applications culture. We need to reinforce the importance of a collaborative environment that develops and fosters teamwork as the means to accomplish the EROS mission. Teamwork requires an organization and management committed to open communication at all levels of EROS science and applications, between junior and senior researchers, between technical and scientific staff, and between government and contractor personnel. We share common goals, and so we must constantly discuss those goals, our expectations, and ways to improve the quality and relevance of our projects. Teamwork must be based on open communications and the sharing of responsibilities and successes. Some of the steps that could improve internal communications include:

- To the extent possible given contracting rules, all science staff, government or contractor, should be centralized within the building. At a minimum, USGS science staff should be consolidated.

- Establish regular topical science discussions (e.g. "brown bags") to explore opportunities for new research or improved approaches to land change science topics.

- Actively support an EROS science seminar series with the explicit goal of stimulating cross-center and -project collaboration.

- Hold an annual science retreat in which the staff review their work and constructively address ways to improve the effectiveness and impact of projects. Open forum discussions on new research opportunities should be a part of the annual retreat.

- Reward and openly celebrate staff and project successes. Recognition of major accomplishments is an important way to communicate the importance of our work.

In addition to improving communications, incentives for cross-project integration and synthesis should be established, more effort should be made by senior RGE researchers to provide intellectual leadership and mentoring to other EROS science and applications staff, and efforts to document and advertise the impacts of EROS staff and their products and service activities should be initiated.

### 5.5 Communications

In addition to improving science and applications group internal communications, sharpening the communications of our science mission and project accomplishments across EROS and throughout the USGS is also needed. For example, we need to make sure that EROS senior staff and USGS decision makers (e.g., USGS Associate Directors, Program Coordinators, and key USGS Center Directors) understand the scope and importance of our land change science capabilities. The science and applications staff have to learn to shift their communications from emphasizing how we do our projects to explanations on why we are doing specific research and what we are learning. Also associated with improving communications is to rationalize and modernize the EROS science web presence. We need to move to presenting a more current and integrated perspective on EROS science and applications activities, with emphasis on presenting science from an EROS mission perspective.

The goal should be to raise the level of visibility of science and applications by emphasizing the value brought to the EROS and USGS mission and the impacts of our activities internally and externally. The internal seminar series mentioned previously must be an important part of our communications foundation. It is our responsibility to explain how science and

applications advances the EROS mission and how a science culture enriches and strengthens EROS.

### 5.6 Emphasizing Ideas

We must embrace the democracy of science and encourage all staff at all levels and employers to constructively challenge ideas and offer new approaches. If we understand that we must continuously pursue transformative ideas and practices, we will elevate the impact of our science and applications activities. This means that we must challenge projects and people to develop better strategies to increase the impact of their work. This should be viewed by every member of the science and applications staff as a personal challenge to improve their stature, impact, and the value of their work. Self-evaluation and comparison of project goals and approaches to today's state-of-the-art is needed. Each project should raise this question: where will this project be in five years and what will it take to reach those goals?

Individual initiative and creativity must be encouraged. Every member of the EROS science and applications community is encouraged to take the initiative to assert their perspectives on how to impact the EROS mission through their ideas and projects. This includes encouraging the proactive identification of new science and applications approaches and topics. The development of white papers is an appropriate means to refine, communicate, and advocate for relevant ideas that have the potential to elevate EROS science and applications.

### 5.7 Improved Planning

Science and applications planning should be pursed as a hierarchical venture that starts with this science strategy, is clarified by broad science position papers on specific topics, and transitioned into an implementable investigations through specific project plans. All plans should be peer reviewed, shared, and kept up-to-date. Good plans serve as a roadmap that can keep an investigation focused. The temptation to pursue interesting tangents can be avoided if project plans provide an intelligent layout of the critical research and development issues that must be solved. The plans can be particularly important in guiding decisions on external funding. Too often, reimbursable income is pursued in order to pursue a tangential or curiosity-based topic. Unfortunately, that can put other project objectives at risk due to diverted resources and subsidy of the reimbursed work with other project funds. That said, pursuit of funds via competitive or unsolicited proposals remains and important researcher responsibility. Success validates the quality of work and ideas, and augments the capabilities of projects. Success brings positive visibility. However, the topics we pursue must align with the goals contained in project plans.

### 5.8 Increasing External Collaboration

The old adage that you are the average of your five closest friends is relevant to the EROS science and applications program. Our reputation is reflected in the quality and prestige of our external partners. An insular organization cannot compete nationally. In the early post-World War 2 era, visionary leaders concluded that national competitiveness was based on strengthening the national science infrastructure through a triangular relationship involving government, industry, and academia. That concept is still valid. We have many examples of strong external industry and academic partners that have brought great value and impact to all corners of EROS. As part of our effort in increase science and applications excellence, we need to strategically and tactically build new partnerships and strengthen existing ones. Partnerships with appropriate universities have the potential to not only bring fresh ideas into our research, but may also to lead to greater access to graduate students and post-doctoral researchers that may be EROS workforce candidates.

Research strategies and project plans must identify partnership opportunities. Initial efforts for engagement may be informal, but as funds are identified within project groups, partnerships could become more institutionalized.

## 6.0 Priority Actions

The following priorities are needed to address the science goals outlined in this plan. These priorities are intended to move ahead in implementing LCMAP capabilities and to improve the impact of science and applications within EROS, the USGS, and the international land change science community. This requires updating the EROS science and applications program, improving the EROS science culture, and sharpening our science and applications focus. Priorities and milestones include:

- Implementing a new EROS science and applications organization that aligns with the science goals and LCMAP objectives, and places emphasis on innovation, relevance, impact and accountability (initiate by October 2015).

- Developing comprehensive and integrated research plans for the three science goals and the seven science focus areas. Plans should include the definition of a plausible science niche, clear identification of research goals and objectives, definition of the general research elements, determination of deliverables, key collaborators, required resources, workforce needs, the LCMAP relationship, and connections with the other EROS science focus areas (internal review starting in February 2016, completed by June 2016).

- Based on the science plans, consolidation of projects into more cohesive, high impact teams focused on the broad objectives of the EROS science strategy and the specific science focus area goals and objectives (beginning in August 2016).

- Preparing and implementing an EROS science and applications workforce plan that can guide the definition, recruitment, and selection of our future staff (complete plan by September 2016 and begin implementation). This plan should include a goal to increase the percent of USGS science and applications branch staff with PhD's to 50 percent by 2020.

- Developing appropriate strategic and tactical science and applications partnerships with recognized land change science leaders and organizations (ongoing).

- Achieving the initial operational status of the LCMAP land change detection capability and initiate the operational provision of historical and contemporary U.S. land cover products. This includes the ability to detect change as it is occurring and provision of tailored land cover products that enable a new level of land change understanding (November 2017).

- Developing criteria and initial science content planned for the LCMAP information warehouse (June 2016).

- Establishing annual series of land change science assessment reports that address relevant topics related to land change rates, causes, and consequences. Selected topical reports should be produced beginning in October, 2016, with initial reports on annual land change summaries by December 2017.

- Establishing and implementing a science strategy for the EROS projection component of LCMAP. This strategy should identify an LCMAP-relevant niche, connect to the different science focus areas, and define appropriate external connections (discussions immediately with completion by December 2016).

- Defining and initiating development of global LCMAP capabilities (starting in late-2017).

- In keeping with the EROS Center goal to serve as land change science leaders, EROS science and applications staff will identify appropriate opportunities and define annual goals for expanding their impact within national and international science initiatives (ongoing).

Ultimately, the most important priority for the next five years is to elevate the EROS science and applications program to an internally and externally recognized *bona fide* USGS science center. We must collectively strive to make science and applications considerations an aspect of all EROS decision making. This will be challenging in a Federal environment with funding challenges and in a Center focused primarily on operations. The competitive nature of science funding forces increased emphasis on defining relevant niches and determining how we can compete at a higher level than ever before. This science strategy starts the process but success will depend on taking the broad outline of this plan and translating it into relevant, innovative, and productive science and applications

investigations. We need newer and more innovative thinking and more teamwork than ever before. It is truly everyone's challenge.

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