A PLAN FOR A U.S. NATIONAL LAND IMAGING PROGRAM

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

Future of Land Imaging Interagency Working Group

In memory of Jay Feuquay,
who brought wit, intelligence,
and friendship to everyone around him.

About the National Science and Technology Council

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On The Cover

Landsat 7 imagery of the Grand Canyon in Arizona

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August 2007

Table Of Contents

EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

August 7, 2007

Dear Colleague:

The United States has maintained a continuous record of moderate-resolution land imaging since the launch of Landsat 1 in 1972. These data have proven to be indispensable for the scientific and operational monitoring of the Earth's land surface for a wide variety of purposes by the U.S. and by numerous international partners. This unbroken record has been maintained despite the lack of a coordinated long-term program commitment thanks to the dedicated efforts of a number of individuals who planned, launched and operated those spacecraft on an *ad hoc* basis.

The importance of this imagery to the Nation requires a more sustainable effort to ensure that land imaging data are available far into the future. As such, in December 2005, I initiated an inter-agency effort to develop a long-term plan to achieve technical, financial, and managerial stability for operational land imaging in accord with the goals and objectives of the U.S. Integrated Earth Observation System. In response to this directive, the Future of Land Imaging Interagency Working Group was established to develop a plan that identifies options for future civil land imaging data acquisition, establishes an implementation strategy, and recommends a governance and management structure to ensure that future U.S. land imaging needs will be met.

This report represents the results of that work. It presents a set of policy recommendations to achieve a stable and sustainable U.S. operational space-based land imaging capability and to ensure continued U.S. scientific, technological, and policy leadership in civil land imaging and the scientific disciplines it supports.

Sincerely,

John H. Marburger III
Director, Office of Science and Technology Policy

The United States relies on moderate-resolution land imaging for a wide variety of critical observations of the global land surface. The United States has long maintained scientific, technological, and policy leadership in satellite-based land remote sensing for the benefit of the United States and other nations, and this leadership has manifested itself as high-resolution imagery systems that benefit national security and many U.S. commercial purposes, moderate-resolution systems that benefit society in more general but vital ways, and low-resolution systems, originally designed for weather satellites, that can reveal certain characteristics of the Earth over very broad areas. Benefits of a continuous global record of moderate-resolution land imaging include the management of U.S. lands and territorial possessions, domestic agriculture and natural resources, monitoring global change, national security, and other aspects of general U.S. economic welfare. These benefits have been amply validated since the early 1970s by the success of the Landsat satellite series.

While U.S. policies have led to robust and growing markets for high-resolution aerial and satellite land imaging, attempts to foster the commercial development of moderate-resolution satellites have not succeeded. Furthermore, no single Federal agency currently has the responsibility for meeting the Nation's need for operational moderate-resolution data.[1] *The United States is developing a plan to maintain its scientific and technological leadership role in this area beyond the end of the current decade.*

It is proposed that the United States establish a National Land Imaging Program led by the U.S. Department of the Interior to ensure that U.S. land imaging needs are met in the future and to maintain U.S. leadership in civil land imaging and land science, including the development and operation of U.S.-owned operational space assets dedicated to civil land imaging purposes, and that the U.S. pursue a strategy of collaborating with its international partners and other U.S. and foreign commercial entities to augment U.S. capabilities to the level required to meet U.S. operational needs.

[1] *Operational data are provided by systems that are likewise operational, as distinguished from experimental or developmental systems; operational systems use reliable and proven technologies, are designed to provide unbroken streams of data over extended periods of time, and are backed by a commitment to replace any system that fails during operation.*

The Importance and Use of Land Imaging

Space-based land imaging systems of all types are essential because they provide repetitive and synoptic observations of the Earth otherwise unavailable to researchers and managers who work across wide geographical areas, disciplines, and applications. The information derived from such systems complements that obtained from other sources including airborne platforms and ground measurements and observations.

Moderate-resolution satellites are critical for frequent global monitoring of land-surface changes. Imagery at moderate resolution is best suited for detecting the impacts of global climate variability and change, population growth and movement, and changes in land use practices.

As depicted in Table 1, high-resolution aerial and satellite systems provide imaging capabilities from sub meter to 5 meters pixel resolution but are particularly concentrated around capabilities below 1 meter. Moderate-resolution satellites provide imagery from 5-120 meters pixel resolution, and low-resolution climate and weather satellites provide pixel resolution beyond 120 meters (typically from 250 m to 1 km or greater). High- and moderate-resolution systems share the ability to capture surface details of the Earth unavailable from low-resolution satellites. This level of detail makes these satellites particularly

Table 1. Characteristics of Space-based Land Imaging Satellites

Type of Satellite	Spatial Resolution (meters)	Geographic Coverage Swath per Image (kilometers)	Frequency of Repeat Coverage of the Same Location
High-resolution	< 5	10 – 15	Months to years
Moderate-resolution	**5 – 120**	**50 – 200**	**15 – 30 days**
Low-resolution	> 120	500 – 2000	1 – 2 days

Policy Report

useful for a wide range of applications that can be similar but at different scales. The differences among these applications are often directly related to the area of the Earth's surface captured in each image taken by a high- versus moderate-resolution satellite. High-resolution systems are most useful for observing fine detail over relatively small areas, whereas moderate-resolution systems are most useful for capturing regional to global Earth data systematically and repetitively. This difference makes both high- and moderate-resolution satellites unique and highly useful for different purposes and users.

These systems are essential for inventorying and monitoring global agriculture, tracking the status of Earth's ecosystems and natural resources—including impacts of climate variability—and assessing the condition of national energy and transportation systems. In addition, moderate-resolution imagery aids the conduct of military and intelligence operations and is used for disaster mitigation and response, natural resource management, mapping, and many other operational applications of utility and importance to governments throughout the United States and globally.[2]

Federal Government uses of moderate-resolution land imaging data are numerous, broad, and complex. Federal agencies that use these data include: U.S. Department of Agriculture, U.S. Department of Commerce, U.S. Department of Defense, U.S. Department of Energy, U.S. Department of Homeland Security, U.S. Department of the Interior, U.S. Department of Justice, U.S. Department of State/ Agency for International Development, U.S. Department of Transportation, U.S. Environmental Protection Agency, National Aeronautics and Space Administration, National Geospatial-Intelligence Agency, and the National Science Foundation.

Among the moderate-resolution satellite systems developed and flown by various nations, the U.S. Landsat satellite series is unique and unparalleled in the world. Since 1972, Landsat satellites have provided data for both U.S. and global needs, and these data are essential for meeting the needs of many levels of government, including Federal, State, local, and tribal jurisdictions. Such data are critical in national and global agricultural assessments performed by the U.S. Department of Agriculture and provide essential data for U.S. international agencies. For example, the U.S. Agency for International Development's Famine Early Warning System Network currently uses Landsat imagery for food security applications for numerous nations in Africa, the Middle East, and Central Asia. In addition, numerous U.S. and international land cover programs rely on Landsat data for human health and ecological planning. Landsat data are also used for U.S. national and homeland security operations.

The U.S. Landsat satellite series holds a position of unique and unparalleled importance in the world.

Three characteristics make the existing U.S. moderate-resolution land imaging system unique:

- Landsat is the only moderate-resolution satellite that provides global cloud-free coverage of the entire Earth's land surface on a seasonal basis.
- The radiometric, spectral, and geometric quality of Landsat's imagery is unparalleled and its coverage across several key spectral bands is unique among the world's satellites.[3]
- The 35-year-old U.S. Landsat archive, managed by the U.S. Geological Survey, is a unique repository of satellite imagery, allowing accurate comparisons of natural and human-induced changes on the Earth's surface over several decades.

Land observing satellites are prominently featured alongside other ground and space-based observing systems in the intergovernmental Global Earth Observation System of Systems (GEOSS).[4] As a result of commitments made since 2003 by the United States, several European nations, Japan, India, Russia, China, and other emerging space-faring nations, space-based land observation has been firmly

[2] *See Appendix A: Societal Benefits of Land Imaging.*

[3] *Spectral coverage is important for discriminating features upon the Earth's surface, such as plant type, chemical composition, or moisture content—essential information for many scientific and land resource management inquiries.*

[4] *See www.earthobservations.org for more information.*

established as a scientific capability that is needed to support the development and welfare of Earth's populations, societies, and economies. In response to GEOSS, the United States is planning an Integrated Earth Observation System (IEOS) to serve both U.S. and global needs.[5]

The utility and importance of moderate-resolution land imaging data have been proven for a range of critical applications for civil, military, and intelligence needs, yet *the United States has never established an operational program centered on a moderate-resolution land imaging capability.* Although the Nation has permanent, operational space-based observation programs for weather forecasting and for study of the atmosphere and oceans, there is currently no policy or plan for a parallel land imaging program.

In addition, the United States is no longer the only supplier of moderate-resolution land imaging data. Today, France, Germany, Japan, India, China, and Brazil possess or are building land imaging satellites that, at least in some respects, are similar to the Landsat satellite system (see Appendix B for details of international land imaging capabilities). Over the next few years, these countries intend to increase their systems' capabilities such that they may rival today's Landsat in both quality and coverage. Other nations are joining this list, although these system's data quality, imaging capabilities, or other system characteristics may prevent acquisition of global data on a scale or with a frequency or quality comparable to Landsat. Furthermore, no other nation has an archive of historic land imagery comparable to the 35-year global record the United States maintains from Landsat. Finally, obtaining such data from foreign sources involves reliability and security risks.

Recommendation #1: The U.S. must commit to continue the collection of moderate-resolution land imagery.

This commitment is required to ensure that the Nation's economic, national, homeland, and environmental security are supported by continuing the 35-year global moderate-resolution land imaging data record.

[5] *Interagency Working Group on Earth Observations, "Strategic Plan for the U.S. Integrated Earth Observation System," National Science and Technology Council, April 2005.*

The State of Moderate-resolution Land Imaging in the United States

Despite its long history, the Landsat satellite series has never been considered a truly operational capability. All Landsat satellites have been justified, built, and flown as experimental, scientific research systems with no assurance of the long-term continuity of the data.

For close to 30 years, the policy of the federal government has been to encourage commercialization of space capabilities and systems including Landsat.[6] Despite previous attempts to commercialize moderate-resolution data-collection in the U.S.[7], a viable commercial option has not yet emerged even though the products are used widely by governments, government support contractors, universities, private for-profit, and nonprofit organizations.[8, 9] Some of the challenges that have inhibited commercialization include: lack of expected market growth, higher costs for Landsat products (to help cover investment costs and profit expected by the private sector), failure to realize operating costs savings, inhibited applications of the data, and reduced data use by the end-users resulting from these cost factors.[10]

Despite attempts to commercialize Landsat, a viable commercial option has not yet emerged.

[6] *"National Space Policy," Presidential Directive NSC-37, 1978; "Civil Operational Remote Sensing" Presidential Directive NSC-54, 1979; Land Remote-Sensing Commercialization Act, Public Law 98-365, 1984; Landsat Remote Sensing Policy Act, Public Law 102-555, 1992.*
[7] *"Toward New Partnerships In Remote Sensing: Government, the Private Sector, and Earth Science Research," National Research Council of the National Academies, 2002, 9-13.*
[8] *See Exhibit 9: "American Society of Photogrammetry and Remote Sensing Survey on the Future of Land Imaging," Reprint from Photogrammetric Engineering & Remote Sensing, January 2007, 5-9.*
[9] *See Exhibit 4: "The Landsat Program: Its Origins, Evolution, and Impacts," Reprint from Photogrammetric Engineering & Remote Sensing, July 1997.*
[10] *Ibid.*

The difficulty of commercializing these capabilities was addressed in a 2004 memorandum from the Office of Science and Technology Policy (OSTP):

> "Landsat is a national asset, and its data have made—and continue to make—important contributions to U.S. economic, environmental, and national security interests...[but] the future availability of imagery from the existing Landsat satellite constellation remains uncertain….The lack of viable commercial markets for Landsat data led to the cancellation of plans to pursue Landsat data continuity as a public-private partnership. Any disruption in the continuous availability of Landsat imagery, products, and value-added services will adversely affect governmental, international, and other users and may limit use of the global data set for certain types of scientific analysis.
>
> In order to maintain Landsat's legacy of continual, comprehensive coverage of the Earth's surface, the United States Government will transition the Landsat program from a series of independently planned missions to a sustained operational program and establish a long-term plan for the continuity of Landsat data observations."[11]

Even with immediate action, the U.S. anticipates a gap in Landsat data for an unknown period of time.

High-resolution satellite systems, used predominantly on behalf of the national and homeland security communities and U.S. commercial interests, have surmounted many of these difficulties. Since 2000, the National Geospatial-Intelligence Agency has made commitments of approximately $1.5 billion to purchase U.S. and foreign commercial, high-resolution satellite data and to maintain a viable U.S. commercial remote sensing industry, consistent with U.S. space policy.[12]

[11] See Exhibit 5: "Landsat Data Continuity Strategy," OSTP Memorandum of August 13, 2004.
[12] See U.S. Commercial Remote Sensing Space Policy, April 25, 2003 and the U.S. National Space Policy, August 31, 2006 at www.ostp.gov.

While past efforts to commercialize moderate-resolution satellites have not fared well, public-private partnerships or solely private endeavors may be realized in the future when the challenges mentioned above, as well as others, are adequately addressed. The currently functioning U.S. moderate-resolution satellites (Landsat 5 and 7)[13] are operating beyond their design lifetimes in degraded status and are subject to failure at any time. Because of fuel limitations, neither satellite is expected to operate beyond 2010. These satellites will be succeeded by the Landsat Data Continuity Mission (LDCM), scheduled for launch in 2011 at the earliest. Because of technical problems with the existing Landsat satellites and the lack of an operational program commitment, a gap in U.S. moderate-resolution land imaging data, thought by many to already exist for certain applications,[14] will only worsen before the launch of the LDCM.

Despite efforts since the 2004 OSTP memorandum was issued,[15] the United States still has no national program that includes, as a part of its charter, the launch of a successor mission to LDCM, including the potential need to deploy a replacement satellite should LDCM fail at launch or early in its design life. This document addresses those circumstances and responds to the concern expressed in the 2005 *Strategic Plan for the U.S. Integrated Earth Observation System*:

> "…the main source of our current land observation data, Landsat, is facing technological obsolescence, mission life limitations, and funding challenges."

Notwithstanding the wide use of Landsat data, the Nation will likely continue to experience partial or complete Landsat data gaps for several more years.

[13] Landsat 5, launched in 1984, and Landsat 7, launched in 1999, are currently functioning on orbit. Landsat 6 failed at launch. See http://landsat.usgs.gov/.
[14] See Exhibit 9: "American Society of Photogrammetry and Remote Sensing Survey on the Future of Land Imaging," Reprint from Photogrammetric Engineering & Remote Sensing, January 2007, 5-9.
[15] Plans to install a Landsat-type imager on the National Polar-orbiting Operational Environmental Satellite System (NPOESS), a sustained operational weather satellite, were cancelled in December 2005, when that approach was found to be technically and fiscally infeasible.

Achieving Technical, Financial, and Managerial Stability for U.S. Operational Land Imaging

It is essential for the United States to maintain continuity in moderate-resolution land imaging. However, U.S. Government-owned and operated satellites may not be the only means to meet U.S. operational land imaging needs for moderate-resolution data. Options for meeting ongoing U.S. needs for moderate-resolution land imaging data include: 1) a U.S. Government-owned system; 2) a U.S. public-private partnership; 3) reliance on international sources of data; 4) a U.S. commercial program (should it become viable); and 5) a combination of these options.[16]

The U.S. should maintain a leadership role in moderate-resolution land imaging.

Several key objectives compel the United States to develop and launch moderate-resolution Landsat-type satellite systems in the future:

1) To ensure that U.S. civil land imaging data needs are met in a reliable and secure manner with objective, unbiased results, particularly when fulfilling sensitive U.S. operational national and homeland security requirements.
2) To ensure that U.S. technologies in land imaging continue to advance across a wide array of potential systems and capabilities.[17]
3) To maintain U.S. technical capabilities in this area and the ability of U.S. industry to compete for expanding worldwide markets in land imaging and land imaging science.
4) To maintain a U.S. science, technology, and policy leadership role for civil land imaging in the conduct of U.S. foreign policy.

[16] See Appendix B: Options for Maintaining U.S. Civil Land Imaging Data Availability.

[17] Potential capabilities in land imaging include radar, lidar, hyperspectral, magnetic, and other forms of imaging and sensing that could prove beneficial to U.S. operational users.

U.S. capabilities no longer meet the increasing demand for frequent, high-quality multispectral imagery.

Already, U.S. capabilities no longer meet the increasing demand for frequent, high-quality multispectral imagery. LDCM will provide data over the United States once every 16 days, the same rate as each of the current Landsat satellites. However, this 16-day revisit time will cause a decrease in U.S. land imaging coverage as compared to the 8-day repeat cycle that results from the staggered orbits of the two existing Landsat satellites. Furthermore, although a comprehensive assessment of user requirements is needed and must be conducted, it is already known that many U.S. users would benefit from global land coverage as frequent as every 2-4 days, particularly for time-sensitive uses in agriculture, disaster management, and national and homeland security operations. Yet, expanding the number of U.S. satellites deployed might be prohibitively expensive.

This study explored whether moderate-resolution land imaging requirements might currently be met by a commercial enterprise. Discussions with commercial data providers during the course of this study confirmed that no viable commercial market currently exists now for Landsat-type imagery in the U.S. However, as U.S. demand for high-resolution imagery expands, as indicated by current market forecasts, and as space technologies evolve, U.S. commercial interests may reconsider whether to enter the moderate-resolution land imaging data market.[18] It is conceivable that a combination of high-resolution and moderate-resolution imagery may be commercially viable even if moderate-resolution imagery alone is not. Commercial viability of moderate-resolution imagery markets should be re-evaluated periodically. In addition to data provision, the private sector plays an essential role in the development and delivery of value-added imagery products, and that is an appropriate and essential commercial role as well.

[18] See Appendix B: Options for Maintaining U.S. Civil Land Imaging Data Availability.

Likewise, although the Nation should not rely on foreign-owned satellites as a primary source of data, foreign systems could be used to augment U.S. capabilities. The United States should not depend primarily on foreign satellites for global, moderate-resolution land data because the United States would become vulnerable to data interruption as a result of changes in a collaborator's capabilities or commitments, political conflict, or other strain in international relations, and may become dependent upon technologies developed and owned by foreign entities.

Furthermore, resources could be used more efficiently through international coordination. Foreign-owned government or commercial systems may be used to augment U.S. imaging capabilities through collaborations or partnerships aimed at reducing duplication of satellites and in areas of technology the United States chooses not to pursue. Today, for example, the United States has not chosen to pursue operational radar, lidar, or hyperspectral land imaging capabilities even though these capabilities are being developed by other nations.

The United States should conduct a thorough inventory of U.S. land imaging needs sufficient to establish a baseline of specific land imaging technologies in which the U.S. Government should invest in the future. In the meantime, the United States should seek to maintain a core operational set of capabilities matched to critical U.S. needs for moderate-resolution data, using U.S.-owned satellites and augmented by data acquired from U.S. or foreign sources.

Recommendation #2: The United States should establish and maintain a core operational capability to collect moderate-resolution land imagery through the procurement and launch of a series of U.S.-owned satellites.

The core U.S.-owned operational capability should be complemented and supplemented through commercial data purchased from U.S. sources when and if available and from international partnerships, collaborations, and data exchanges with foreign governments and commercial sources as available and appropriate.

U.S. moderate-resolution land imaging management efforts are currently shared among the National Aeronautics and Space Administration, a satellite technology development agency; U.S. Geological Survey, a satellite operating and data archive/distribution agency; and several agencies that procure and use various types of land-imaging data without coordination or collaboration. In addition, while some agencies develop in-house applications for remote-sensing data for use in operations or research, several agencies that could benefit from additional use of land imagery or its applications remain underserved. Finally, the lack of long-term funding for ongoing development and launch of moderate-resolution, multi-spectral land-surface sensors and other land imaging technologies has hindered the transition of U.S. scientific research capabilities and demonstration technologies into operational land monitoring systems available for broad, operational use by the United States.

The critical need for management stability and centralization might be addressed via several options including: relying on a single agency to manage U.S. land imaging; multiple agency management; an integrated program office; a U.S. national commission; or allowing each Federal agency to procure its own data without additional support or coordination.[19]

Current management efforts of U.S. moderate-resolution land imaging are shared among agencies.

The preferred option is to have a single agency responsible for technical leadership, gathering user requirements, developing and promoting user applications, and managing satellite and data acquisitions and resources, including long-term archiving of critical land imaging data sets.

Because of its extensive history with Landsat and recognized expertise in land remote sensing data calibration and management, its reputation in

[19] See Appendix C: Governance of the Future of U.S. Land Imaging.

The U.S. Department of the Interior is judged to be the most appropriate department to lead the new National Land Imaging Program.

land science, and its established role as manager of U.S. lands and other territorial interests, the U.S. Department of the Interior is judged to be the most appropriate Federal department to become the lead agency for establishing the National Land Imaging Program (NLIP). However, in this role, the Department of the Interior should be viewed as the leader and coordinator of active Federal agencies and should be advised by other Federal agencies, non-federal stakeholders, and data users in order to ensure that the broad interests of the user community will be met. The NLIP will exercise leadership in collaboration with international and non-federal partners.

Recommendation #3: The United States should establish the National Land Imaging Program, hosted and managed by the Department of the Interior, to meet U.S. civil land imaging needs.

Implementation of the National Land Imaging Program

The establishment of the National Land Imaging Program (NLIP) will require enactment of a series of provisions regarding the goals, organization, and operation of the program.

- The NLIP would lead, coordinate, and plan for future U.S. civil operational moderate-resolution land imaging, including managing the civil operational moderate-resolution land imagery needs of the Nation, to promote the widest beneficial use of land imagery for civil purposes in the United States and to ensure that land imagery data are available to all public and private users throughout the United States.
- The NLIP would be led by the U.S. Department of the Interior and would report to the Secretary or an Assistant Secretary of the Department, consistent with national responsibilities assigned to this program.
- The NLIP would recognize and accommodate the critical role that other U.S. Federal agencies play in serving U.S. moderate-resolution land imaging data needs. NLIP would convene a Federal Land Imaging Council composed of the National Aeronautics and Space Administration, the National Geospatial-Intelligence Agency, the Departments of Defense, Commerce, Agriculture, Homeland Security, and State and other agencies as appropriate to coordinate these needs. This Interagency Council would advise NLIP on its future land imaging needs and program objectives.
- In concert with other U.S. agencies and consistent with the economic, scientific, security, and foreign policy interests of the United States, the NLIP would acquire global, moderate-resolution land imagery data, manage all U.S. civil moderate-resolution land imaging technologies, satellites, and systems needed to sustain future U.S. capabilities in this area, ensure archival preservation of U.S.-acquired moderate-resolution land imagery, and promote the application and use of civil land imagery on behalf of the United States.
- The NLIP would ensure that all U.S. needs for civil moderate-resolution land imaging data are met and enact policies to ensure ease of access to affordable civil operational land imaging data for all users.
- The NLIP would maintain ongoing assessments of user needs and advanced technologies in remote sensing, including communication with private, nonprofit, academic, commercial, and international users, U.S. state and local government, and the satellite and land imaging data industries.
- The NLIP would conduct a program of field-based research, development, and training to promote and expand the range of uses of moderate-resolution land imagery and related products to meet public needs.
- The NLIP would have the authority to negotiate international agreements, in coordination with the U.S. Department of State, when needed, to augment U.S. civil operational moderate-resolution land imaging systems and capabilities.
- The NLIP would recognize and accommodate the critical role that commercial, state and local

government, academic, and other nonprofit users play in the conduct of national affairs and how these users perform their roles in American society. The Department of the Interior would convene a Federal Advisory Committee on Land Imaging under the rules of the Federal Advisory Committee Act (FACA) to provide input and advice to the NLIP.

- NLIP will ensure that, consistent with the 1992 Land Remote Sensing Policy Act (15 USC 5601), development of the remote sensing market and the provision of commercial value-added services based on remote sensing data should remain exclusively the function of the private sector.
- The NLIP would coordinate future civil operational moderate-resolution land imaging programs and activities with other U.S. Federal agencies through the auspices of the U.S. Group on Earth Observations (USGEO).

Implementation Timeline

Within the first eighteen months after the establishment of the NLIP, the U.S. Department of the Interior would accomplish the following steps:

- Establish a policy and program management office or offices to manage NLIP.
- Develop charters for a Federal Land Imaging Council and a Federal Advisory Committee focused on the future needs and capabilities of U.S. civil moderate-resolution land imaging.
- In coordination with the Federal Land Imaging Council and the Federal Advisory Committee, define a core operational capability for the U.S. moderate-resolution land imaging system.
- Develop a strategic plan for U.S. civil operational moderate-resolution land imaging, including a technology plan to meet future needs beginning with the first flight of a Landsat-type national capability.
- Formalize a governance model that would be used by U.S. Federal agencies to coordinate U.S. civil operational land imaging affairs and identify the necessary suite of interagency agreements and memoranda to accompany that model.
- Set forth the interagency agreements and protocols that will be used to acquire future civil operational moderate-resolution land imaging data from international sources.
- Initiate a comprehensive index of current U.S. operational moderate-resolution land imaging technical requirements and capabilities, based on a national inventory of U.S. needs and applications of civil operational land imaging data.

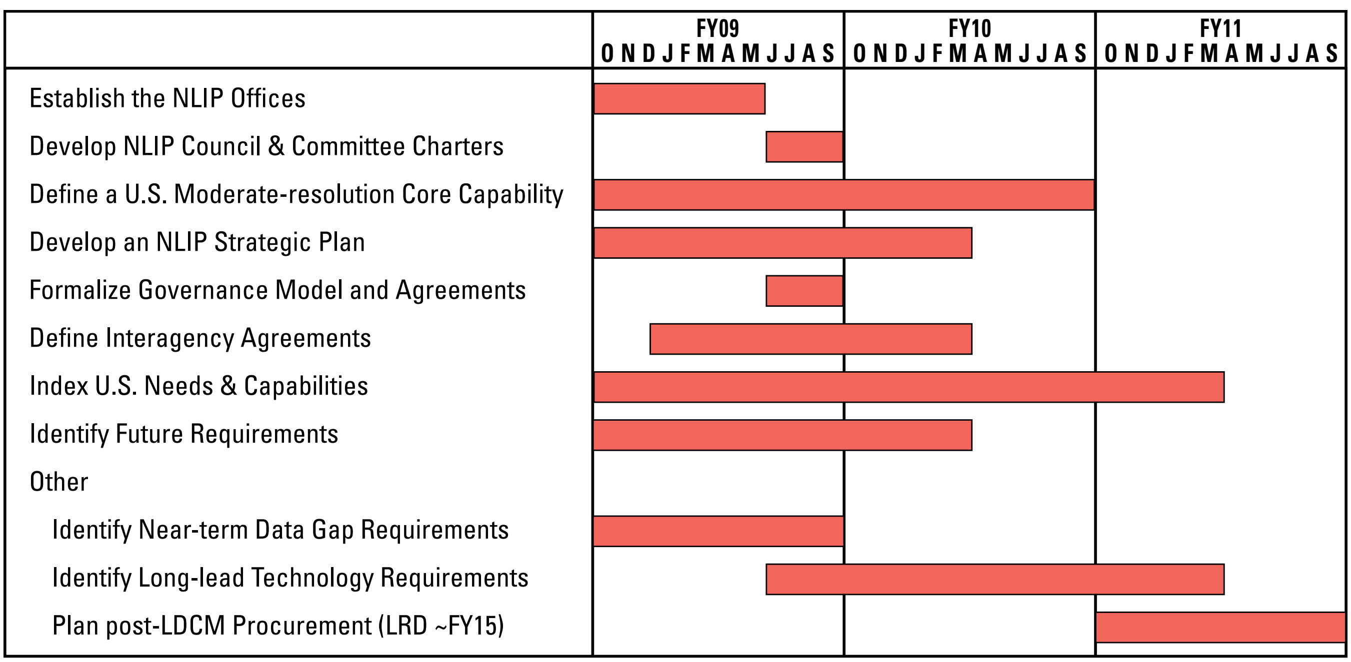

Figure 1. Initial timeline to establish the National Land Imaging Program (NLIP)

Appendix A:
Societal Benefits of Land Imaging

Introduction

The global land surface covers approximately 150 million square kilometers or about 30 percent of the Earth's surface. Humans occupy or otherwise use roughly 80 percent of the land surface including the 40 percent converted to agriculture.[1] The global population reached 6 billion in 1999 and is projected to increase to 9 billion by 2050. Nearly all of this increase will be in Africa, Asia, and Latin America.[2] To feed and shelter the planet's growing population, extensive and intensive land use has been required, but the environmental degradation caused by these requisite activities is diminishing the planet's capacity to sustain needed food and fiber production and fresh water supply. Foley et al. (2005) states "There is an increasing need for decision-making and policy actions across multiple geographic scales…. The very nature of the issue requires it. Land use occurs in local places, with real-world social and economic benefits, while potentially causing ecological degradation across local, regional, and global scales."[3] Land imaging from moderate-resolution Earth-observing satellites offers the critical and irreplaceable capability to observe land use and land use change across those scales.

The Importance of Land Imaging

Space-based imaging systems are able to observe large areas of the Earth's surface, including its oceans and remote lands, and thereby provide a comprehensive planetary perspective that would be otherwise unavailable. Since 1960, the U.S. has flown a wide range of civil remote sensing and imaging systems in space. These systems complement other observational technologies, such as balloons, aircraft, sounding rockets, and ground-based systems used for centuries in science, mapping, and military affairs. Among these imaging systems, land observing satellites play a unique role. Whereas most observational satellites are used for weather prediction and Earth climate studies, land observation satellites are used to manage the affairs of human populations, cultures, and societies in a more direct manner. Moderate-resolution land imaging systems are useful for a wide range of societal purposes, from natural resource monitoring to military planning. Data from such satellites have proved useful for monitoring conditions in U.S. cities, farm and ranch areas, coastal sea and ice zones, and other remote terrain—but that is just scratching the surface.

Land imaging represents several coinciding trends that are poised to transform how technology might be used for the benefit of human society. Just as the convergence of computational and communications technologies transformed human interpersonal and professional correspondence with the advent of email and the Internet, land imaging promises to transform how image-based information about the Earth can be used to better understand, regulate, and manage societal affairs upon the Earth's surface. Borne of many decades of research and operational application using surveillance and reconnaissance balloons and aerial systems, satellite imagery has been used since the dawn of the space age to support and often to redefine many aspects of how societies are managed, including mapping, resource management, and national security. Typically, these applications are hidden from public view since they are practiced by technical communities (e.g., remote sensing and photogrammetry, geographic information systems, and defense and intelligence analysis). But increasingly, general public awareness of the utility of satellite images of the Earth has grown and today applications such as GoogleEarth™ and Microsoft's Virtual Earth™ have become accepted tools for everyday use in households throughout the world.

How is Land Imagery Used?

In its most advanced state, space system technology makes its most significant, beneficial, and profound contribution to society when it feeds data and information directly into the process of data integration, analysis, and condition trending related to predicting or mitigating risks to human populations and cultures or to Earth's natural systems.

[1] Jonathan A. Foley et al., "Global Consequences of Land Use," Science, 22 July 2005, 309: 570-574.
[2] National Research Council, "Beyond Six Billion," National Academies Press, 2000, p 2.
[3] Foley et al., 2005.

One such model of how a system and data acquisition strategy can be tied to the data analysis and prediction systems needed for forecasting is shown in Figure A-1.

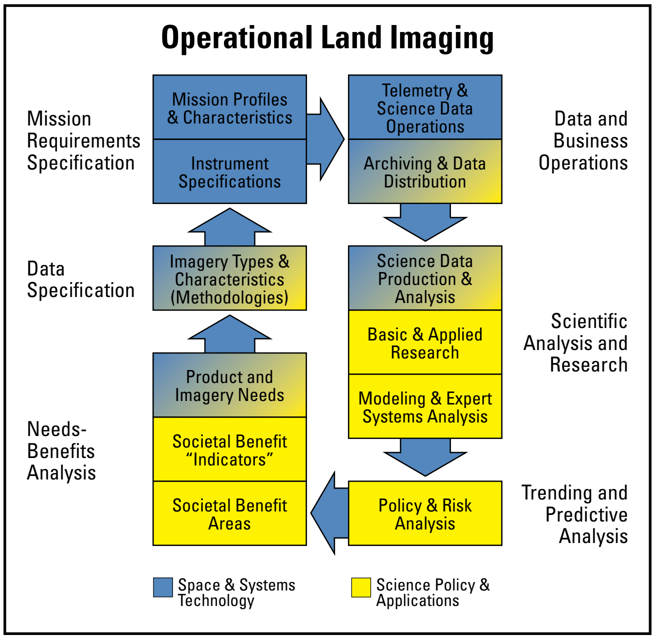

Figure A-1. The cycle of societal benefits, data collection, and data use. Societal benefits require certain types of data, which are obtained by purchasing data or launching Earth observation technologies. The data from those instruments are processed, distributed, and archived, and subsequently used to address the societal needs.

For many years, much of the justification for land imaging was derived from its perceived contribution to, or augmentation of, climate and environmental research. The broad, synoptic views of the Earth's surface that moderate-resolution land imaging provided, taken at a level of resolution sufficient to detail human-induced changes such as urban growth, deforestation, infrastructure development, and land use change, proved invaluable to studies of anthropomorphic effects upon climate change.

However, land imaging satellites have immediate and direct benefit to economies and societies independent of the weather and climate prediction. Weather and climate research satellites typically image the Earth at resolutions from 250 meters to 1 kilometer or more. These resolutions are best suited to the types of measures needed to observe cloud formation, density, and type, to predict wind speed and storm direction, or to conduct very frequent but large sampling of data about conditions in the troposphere and biosphere that are most immediately important to monitoring and studying Earth's climate.

But land imaging as a body of professional and scientific disciplines also owes its heritage to another body of the sciences, including geography, geology, agronomy, civil engineering, urban planning, and military science. Land imaging is often characterized as belonging to the discipline of geospatial science, an operational science related to map-making that also supports these other civil and applied science disciplines. However, land imagery and the data derived from land imagery are used in many ways that are only loosely represented by the processes of map-making and geo-locating of physical surface data.

Satellites and other imagery systems used for land imaging place a premium on acquiring high-resolution images of the Earth in lieu of providing frequent coverage of the whole Earth. Land imaging satellites are optimized to capture very high-resolution (sub-meter), high-resolution (1-3 meter), or moderate-resolution (5-120 meter) images (see Figure A-2 and Plate A-1). These technologies place a premium on gathering the highest clarity data possible about physical features, natural and human-made, on the surface of the Earth. The areas highlighted in red in Figure A-2 illustrate current U.S. operational capabilities and the moderate-resolution land imaging range. Note that the pending NOAA VIIRS sensor will meet most of the low-resolution land imaging requirements, and high-resolution systems are provided by U.S. commercial firms. But moderate-resolution systems have only been managed episodically by the U.S., and no U.S. plan for moderate-resolution *operational* capabilities has ever been developed.

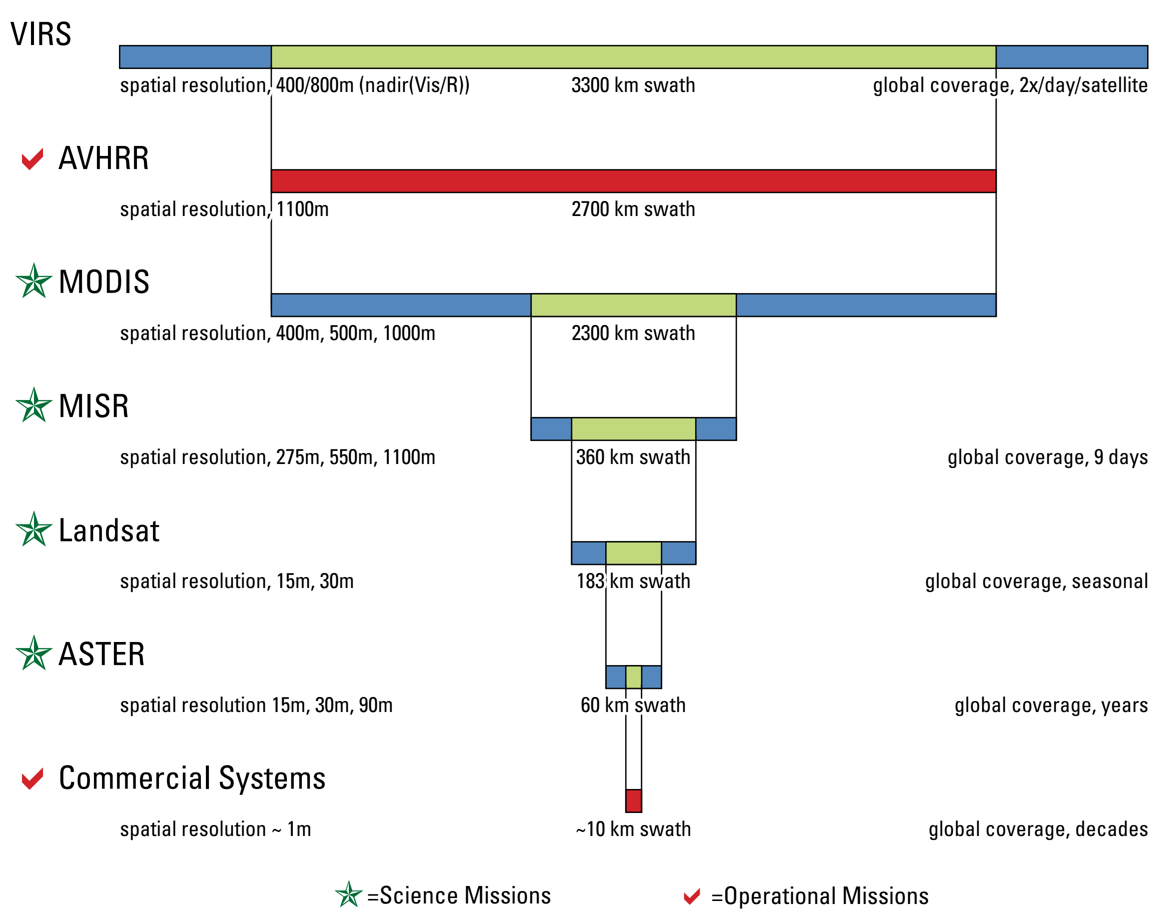

Figure A-2. Range of U.S. land imaging spatial resolutions

Observations across multiple scales serve essential purposes and moderate-resolution imaging should be considered a core capability in the arsenal of operational systems. Coarse-resolution sensors (e.g., the MODIS instruments aboard the Terra and Aqua satellites that capture images with 250-m to 1-km spatial resolutions) provide frequent, near daily coverage of the Earth's surface. These observations are needed to track large-scale dynamic processes such as snow accumulation and melt, the regional green-up and senescence of vegetation, and annual extension and retreat of ice sheets—processes that potentially reflect a changing climate. At the other end of the spectrum, commercial satellite systems provide images of specific small areas (about 15-km swath widths) with sub-meter spatial resolution. These images resolve detailed infrastructure such as roads and buildings and are valuable in national and homeland security applications.

It is at the intermediate (moderate-resolution) scale, however, where land use decisions and consequences can best be observed. Land is typically managed on a small parcel basis, one farm field, forest plot, or housing development at a time. These decisions integrate over the landscape scale with regional to global consequences that persist on a seasonal to annual basis. The synoptic view afforded by moderate-resolution satellite systems best enables the impact of local and regional land use and land management practices to be observed in the context of their large-scale and local consequences.

Current space and ground system technologies, including ground and space telecommunications and space-based data handling technologies, preclude the use of the highest-resolution capabilities available to gather and transmit data on a highly frequent or "wide area of coverage" basis. The extremely high volumes of data that a high-resolution, global-coverage satellite system would produce would exceed the capacity of today's space and ground communication systems. For that reason, moderate-resolution systems such as Landsat fit a special niche between very high-resolution systems useful for capturing very narrow-view images of the Earth and very low-resolution systems that do not capture a sufficient level of detail to detect "human-scale" features on the Earth.

Landsat is designed to provide "relatively high" resolution images of the Earth (thus its designation as a moderate-resolution satellite) and "relatively frequent" coverage of the whole Earth (thus its typical classification as a research satellite dedicated to climate science), so it falls in between high- and low-resolution imaging systems. As such, Landsat is designed to satisfy a broad range of requirements in both the operational sciences and basic science. Nonetheless, Landsat properly belongs to the operational science community given the breadth of its uses for civil and security applications.

The Societal Benefits of Land Imaging

In 2003, the intergovernmental Group on Earth Observations (GEO) and the Global Earth Observation System of Systems (GEOSS) began a process to identify nine societal benefit areas that are key to the future study of Earth's natural systems and their impact on and consequences to society: [4]

- weather;
- natural disasters;
- ocean resources;
- climate variability and change;
- agriculture and forestry;
- human health and well-being;
- ecological forecasting;
- water resource management; and
- energy resource management.

Each benefit to society has been mapped to general Earth observation requirements (see Figure A-3). Note that medium spatial resolution (termed moderate-resolution in this document) is critical for most of the societal benefits.

[4] *"GEOSS: 10 Year Plan Reference Document," Group on Earth Observations, February 2005.*

Redefining the Purposes for Land Imaging—Toward an Operational Paradigm

The GEOSS list of societal benefits provides an international framework for collaboration and data sharing. However, this list does not fully outline land imaging benefit sectors, particularly the heavy use of land imaging for civil government operations and national security. The Future of Land Imaging Interagency Working Group (FLI IWG) found that many categories of users who acquire and use Landsat data classify themselves as performing work in ways that are not directly associated with the GEOSS societal benefit areas. This result was confirmed by a recent survey of remote sensing data users by the American Society of Photogrammetry and Remote Sensing (ASPRS; see Exhibit 9).

Land imaging sensors observe natural systems (e.g., climate research), relationships between humans and nature (e.g., food/water supply), and human systems (e.g., land development). Viewing imagery use in this way allows for consideration of the many uses that are atypical of the basic sciences. These uses are better considered to be applied sciences or the work of imagery analysts and data consumers who are directly employed in the management of civil society itself, including managing public and private transactions in regional, national, and global economies.

In other words, land imaging, including moderate-resolution land imaging, is critical to civil society not only because of the support it provides for the advanced sciences but because of the work of the many technicians and specialists employed by civil governments and other private and public institutions. These technicians directly manage some aspect of society's physical infrastructure, systems, and resources, often in ways that are directly relevant to the economy. Typical applications include monitoring and assessment of urban infrastructures, facilities, and ports; farms and agricultural areas; railways, bridges and highways; rivers, lakes, and waterways; transportation hubs; military forces and installations; and energy systems and grids. Land observation is also used to gather useful information about local population and building development density, for infrastructure and transportation planning, to assess

Land Imaging Needs for Societal Benefits

Observational Capability for Land Imaging	Improve Weather Forecasting	Reduce Loss of Life and Property from Disasters	Protect and Monitor Our Ocean Resources	Understand, Assess, Predict, Mitigate, and Adapt to Climate Variability and Change	Support Sustainable Agriculture and Forestry, and Combat Land Degradation	Understand the effect of environmental Factors on Human Health and Well-Being	Develop the Capacity to Make Ecological Forecasts	Monitor and Manage Water Resources	Monitor and Manage Energy Resources	National and Homeland Security	Global Change Science
Systematic Coverage of Global Land Surface	Critical	Critical	No or low need	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical
Synoptic Observations - Wide Swath	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical
Multispectral Observations	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical
Medium Spatial Resolution	No or low need	Critical	Moderate	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical
Accurate Radiometry and Geolocation	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical
Data Preservation and Archival	No or low need	Moderate	Critical	Critical	Critical	Critical	Critical	Moderate	Critical	Critical	Critical
Affordable, Publicly Accessible Data	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	No or low need	Critical

Legend: Critical Requirement; Moderate Requirement; No or low need

Figure A-3. GEOSS societal benefit earth-observation requirements

property values and resource wealth, to predict agriculture and forestry yield, or to manage regulatory functions associated with security, treaty, and legal compliance. These factors are directly related to managing societal well-being and economic prosperity.

Although the same list of items also might be characteristic of scientific studies, characterizing these items as factors to be managed, rather than as factors to be studied, clearly differentiates practitioner from scientist and the benefits that accrue from management versus developing a body of scientific opinion that may be related to the work of managers at some later time.

As a result, the FLI IWG has identified three broad themes to be used in grouping and measuring future benefits of land imaging to society:

- Societal Management;
- Human and Natural System Interaction; and
- Security and Compliance.

The FLI IWG is proposing this new classification scheme for the benefits of land imaging since it is clear that land imaging is not only relevant to basic science or to the application of basic research in preserving the natural state of the Earth or studying the effect of natural systems on the human population, but also of great significance as a tool for civil government and economies, similar to the use of Landsat for national security applications.

In other words, Landsat is critical to civil government because of the advanced science it supports as well as the work of the many technicians and specialists who support civil government and society by managing society's physical infrastructure, systems, and resources in ways that are directly relevant to the economy.

The FLI IWG used the above-mentioned broad themes to outline a new set of benefit sectors, listed in Table A-1, to cover the many specific uses of land imaging for societal operations relevant to managing an advanced society and economy. The following section highlights specific examples of benefit sectors outlined in Table A-1.

Table A-1. Benefit Sectors of Moderate-resolution Land Imaging Data

Commerce and Earth Resource Management
- Agriculture, Forestry, and Sustainable Development
- Water Resource Assessment and Management
- Energy Resource and Mineral Wealth Assessment and Management
- Foreign Agricultural Assessment
- Insurance Risk Management

Environmental Monitoring and Assessment
- Land Use Change
- Climate Variability and Change
- Habitat and Wetlands Management and Ecological Forecasting
- Sea Ice, Glaciation, and Snow Pack Assessment
- Erosion Control and Hydrological Assessment
- Deforestation, Desertification, and Salinization
- Urban and Rural Geography and Human Ecology

Civil Operations and Applications
- Land Use Planning and Management
- Resource Conservation and Management
- Wildfire, Coastal Zone, and Flood Plain Assessment
- Natural Disasters Mitigation and Response
- Human Health and Well-Being
- Physical Infrastructure Assessment and Operation
- Navigation and Transportation Planning and Management
- Property Valuation and Assessment

National Security
- Intelligence and Information Gathering
- Homeland Security
- U.S. Military Operations
- Health and Productivity of the U.S. Aerospace Industry

Treaty and Legal Compliance
- Boundary Control
- Property Rights and Assessment
- International Conventions and Treaty Management
- Tax Base Assessment
- Land Use Regulation

Examples from Moderate-resolution Land Imaging Benefit Sectors

Commerce and Earth Resource Management

Food and fiber production are predominant land uses for satisfying elemental needs. To feed over six billion people, 16 to 18 million square kilometers of land are currently under cultivation (an area nearly the size of South America) with an additional 33 to 35 million square kilometers devoted to pasture and rangeland (an area roughly the size of Africa).[5] Changing agricultural practices have been required in recent decades to increase production on these lands to meet the needs of the growing population. Biotechnology, fertilization, herbicide and pesticide application, mechanization, and irrigation, for example, have all contributed to a doubling of world grain production over the last 40 years.[6] However, this increased production has come at a price; resulting environmental damage may threaten the ability to further increase, or even sustain production. Soil salinization from irrigation ruins 1.5 million hectares of arable land per year.[7] Soil erosion reduces productivity, and field run-off carrying sediment and agricultural chemicals pollutes waterways and threatens health. Additionally, the annual fluctuations in productivity due to weather, climate, and society drive the world economy and can quite literally result in feast or famine. For instance, the growing reliance on bio-fuels will affect the supply and demand balance of field crop commodities. Agricultural productivity is managed at the field and farm level with global consequences. Global moderate-resolution land imaging is required to monitor and manage agricultural land use, food production, and the consequences of farm practices.

An analysis of 1999 to 2005 Landsat sales through the U.S. Geological Survey (USGS) provides strong evidence of the primary applications of Landsat data. Historically, Landsat's greatest value appears to be its contribution to agriculture and forestry. Agricultural and forestry applications combined make up the largest operational Landsat user group, accounting for nearly 25 percent of the total number of images sold throughout this period. The most common application appears to be estimating annual agricultural production and national and international forest area. Other applications involve forest health assessments, National Forest planning, and studies of changes in American agriculture.

Cropland area and production statistics developed using Landsat data are the basis for ensuring that agricultural statistics that drive national and global commodity markets are fair and accurate so that the

[5] *Jonathan A. Foley et al., "Global Consequences of Land Use," Science, 22 July 2005, 309: 570-574.*
[6] *Ibid.*
[7] *Ibid.*

economic viability of U.S. agriculture is stable. The U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) has used Landsat data for the past two decades as a key input for developing U.S. crop acreage estimates. Landsat data are used to construct the Nation's area sampling frame for agricultural statistics. This is the statistical foundation for providing agricultural estimates with complete coverage of American agriculture. In addition, NASS uses Landsat data in seven to ten agricultural states per year to improve the statistical precision of crop acreage estimate indicators, especially at the county level in those states.

On a global scale, the USDA Foreign Agricultural Service (FAS) has used land remote sensing resources for nearly 30 years, primarily Landsat, as part of a "convergence of evidence" approach that combines information from Earth observations from space, weather data from satellites and ground stations, historical trends, and ground observations. Together, these observations are used to assess current conditions and make forecasts of agricultural production and yield for all major commodities and for all foreign countries in support of the World Agriculture Outlook Board. As such, these estimates are an Office of Management and Budget (OMB)-mandated Principle Federal Economic Indicator. The significance of producing these estimates and producing them using unbiased, unclassified, repeatable, and timely information, such as that acquired from land imaging, cannot be understated. Every month billions of dollars of commodities are bought and sold based upon the USDA global crop production economic indicator, which is derived and validated using moderate-resolution and other land imaging. The FAS shares its remote sensing data with many of the domestic USDA agencies through the USDA Satellite Imagery Archive (SIA) for a myriad of additional agricultural uses. The major elements of the FAS system and its relationship to societal benefits are shown in Figure A-4.

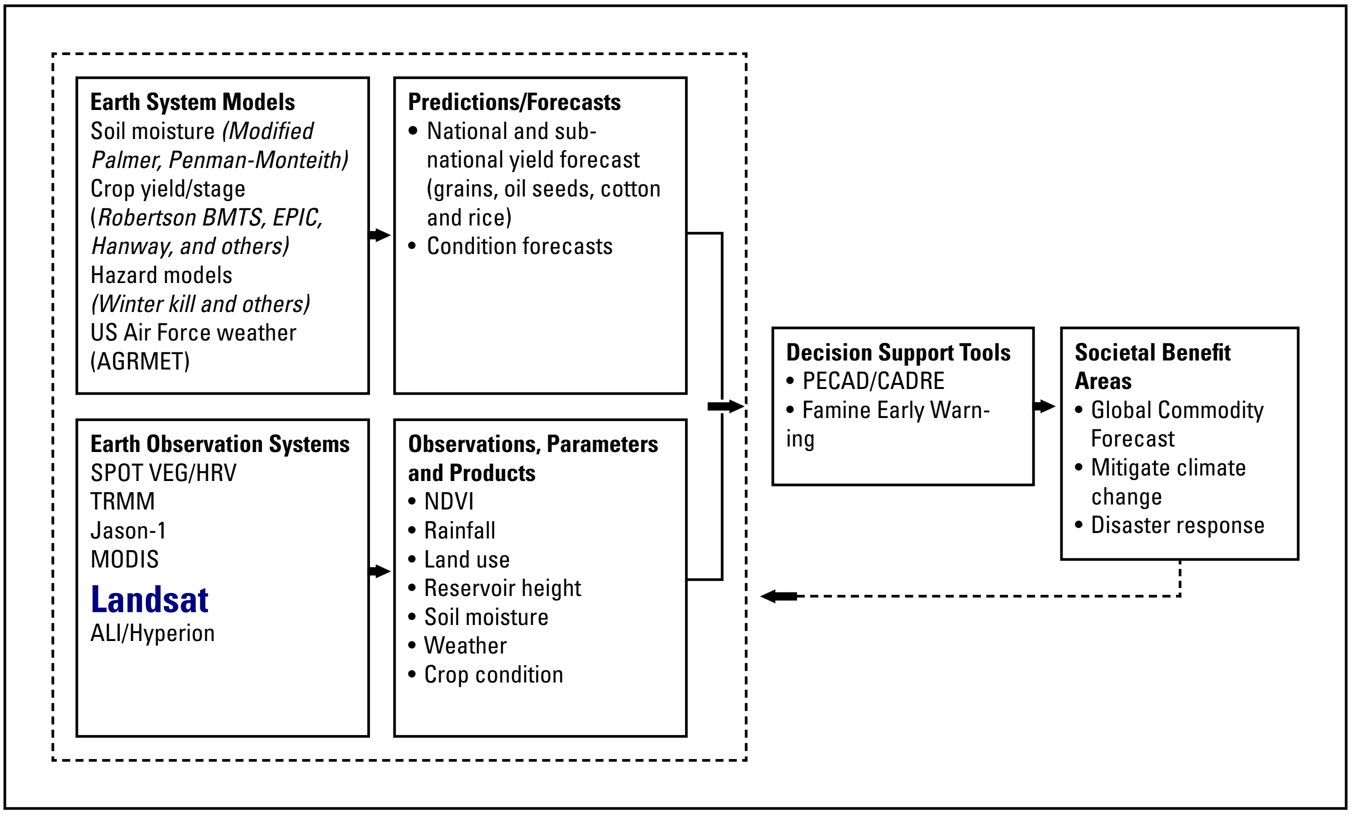

Figure A-4. USDA/FAS global agricultural monitoring components and the societal benefits accrued from the capability

Objective, timely, and reliable information about global agriculture is critical to:

- <u>food safety</u> - baseline food supply information to assess risks and respond to natural disasters (e.g., hurricanes, drought, Asian Soybean Rust infestation) or human-made disasters (e.g., bio-terrorism) that can impact food supply;
- <u>globalization of the U.S. economy</u> - 30 percent of farm receipts ($56 billion) is export revenue, which now is equaled by $56 billion in agriculture imports; and
- <u>mitigation of starvation and malnutrition</u> - early warning systems and agricultural development programs in food-deficit countries where most increases in population growth are projected.

The utility and significance of global agricultural monitoring are illustrated in Figures A-5 and A-6.

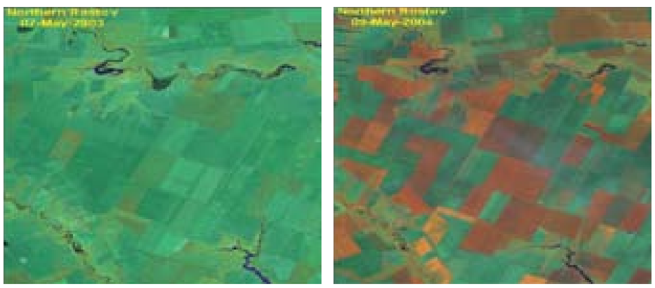

Figure A-5. These two Landsat images show improved condition of Russian wheat in 2004 (right image, red fields) compared to same area the year before (left image) when a severe winter limited production. Source: *One Planet Many People: Atlas of Our Changing Environment*, UNEP/GRID, 2005.

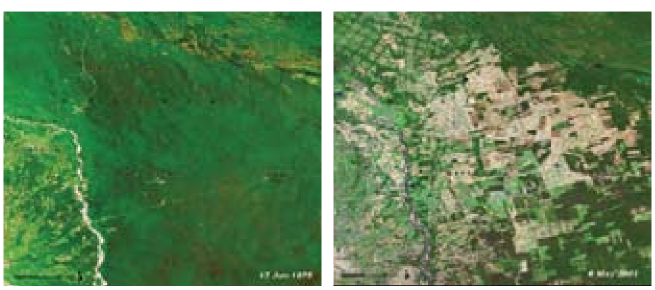

Figure A-6. Two Landsat images of Santa Cruz, Bolivia, reveal agricultural development between 1975 (left) and 2003 (right). Information such as this is vital to evaluate sustainable agriculture, vulnerability to climate change, and the social and economic impacts of agriculture and land use change. Source: *One Planet, Many People: Atlas of Our Changing Environment*, UNEP/GRID, 2005.

Moderate-resolution images are also needed to monitor global forests. Forests provide essential goods and services such as wood, flood control, water purification, recreation, wildlife habitat, and carbon sequestration. Forested lands are changing rapidly. In many areas, particularly in tropical rain forests, agricultural expansion and lumbering have reduced forests. No accurate estimates of the rate and pattern of tropical deforestation in Amazonia were available until Landsat data were analyzed.[8] In other regions such as East Asia, reforestation is occurring and these forests serve as a sink for atmospheric carbon.[9] Forest management and change typically occur in small plots that require Landsat-like data to resolve. The USDA Forest Service, for example, recently used Landsat data to characterize the status and trends in old-growth forests covering over 24 million acres of land in the Northwest Forest Plan area.[10]

Likewise, Landsat-derived national forest plans and maps of burned-forest treatment areas ensure that timely and site-specific information are available. The United Nations Food and Agriculture Organization (FAO) conducts periodic inventories of the extent of global forests. The FAO has historically used the sum of national forest inventories to indicate the extent of global forests and rates of forest change. The global Forest Resources Assessment for 2000 and the upcoming 2010 assessment use Landsat imagery in a global sampling frame in order to compensate for the limitations of national forest inventories and to ensure the most accurate global forestry area and rates of change information available.

Environmental Monitoring and Assessment

A traditionally understood area of Landsat's significance is its use for basic research of Earth's climate changes. Landsat provides the longest and most complete record of the state of the global land surface in existence. As a result, Landsat data are widely used for studies of climate variability and

[8] *Melinda Moeur et al., "Northwest Forest Plan–The first 10 years (1994-2003): status and trends of late-successional and old-growth forest," Gen. Tech. Rep. PNW-GTR-646, Portland, Oregon, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2005.*
[9] *Jonathan A. Foley et al., "Global Consequences of Land Use," Science, 22 July 2005, 309: 570-574.*
[10] *Melinda Moeur et al., "Northwest Forest Plan–The first 10 years (1994-2003): status and trends of late-successional and old-growth forest," Gen. Tech. Rep. PNW-GTR-646, Portland, Oregon, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2005.*

change, and are essential for studying the impacts of climate variability and change on the Earth's surface. The U.S. Climate Change Science Program, representing 15 federal agencies, has identified Landsat as a critical observatory for climate and environmental change research due to the unbroken length of the Landsat record and its importance to identifying the root causes and impacts of climate change.[11] Note that the Climate Change Science Program (CCSP) often defines FLI moderate-resolution land imaging and Landsat imagery as "high-resolution" in strategic plans and other documents.

Landsat has provided key measures that link land change, shifts in the global carbon balance, and increased climate variability. These data are essential for monitoring the relationship between human-induced changes of the planet and climate change. Specifically, Landsat enables researchers to monitor the increase in atmospheric carbon dioxide, correlate it with the increased frequency in extreme weather events, and assess likely future impacts on local communities and the national economy.

Landsat data are used by a wide range of federal climate researchers, including those of the National Science Foundation, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, the Department of Energy, the Department of Health and Human Services, the Department of Defense, the Department of State and the Agency for International Development, and the Departments of Agriculture, Transportation, and the Interior. Likewise, Landsat data are used for climate research by the Smithsonian Institution, the United Nations, and many national and international academic institutes and scientific organizations.

Land cover change and land use practices influence regional changes by affecting net radiation, the division of energy into sensible and latent heat, and the partitioning of precipitation into soil water, evapotranspiration, and runoff. Land cover change monitoring affects the ability to sustain and manage resources vital to society (Figure A-7).

Figure A-7. Satellites can image a much wider area than can be effectively monitored from the ground. This pair of true-color Landsat images compares a clear, clean lake (top) with a lake with poor water quality (bottom). (Images courtesy Upper Great Lakes Regional Earth Science Applications Center)[12]

Landsat data contributed to a recent land use study of Florida crop freezes. The study compared data from past decades to current data, revealing a significant conversion of natural wetlands into agricultural land for the cultivation of winter vegetables, sugar cane, and citrus crops in southern Florida. The study found that, ironically, moving agricultural production of these crops from central Florida further south in order to escape the risk of damaging winter freezes inadvertently led to a draining of wetlands and corresponding increase in the frequency and severity of agriculturally damaging freezes in southern Florida.[13]

Landsat data are also used to monitor the flow of polar ice. Geo-rectified Landsat data help map the movement of seasonal ice flows. Data collected over decades have helped scientists determine relationships between ice acceleration and duration of surface ice melting and have led to the recent conclusion that

[11] William J. Brennan et al., "Our Changing Planet: The U.S. Climate Change Science Program for Fiscal Year 2007," A Report by the Global Change Science Program and Subcommittee on Global Change Research: A Supplement to the President's Budget for Fiscal Year 2007, 2006.

[12] John Weir, "Testing the Waters: Using Satellites to Monitor Lake Water Quality," Earth Observatory, (http://earthobservatory.nasa.gov/Study/WaterQuality/water_quality.html), 11 March 2002.

[13] Curtis H. Marshall et al., "Wetlands: Crop Freezes and Land-Use Change in Florida," Nature, 6 November 2003, 426: 29-30.

glacial sliding is enhanced by rapid migration of surface melt water to the ice-bedrock interface. The indicated coupling between surface melting and ice-sheet flow provides a mechanism for rapid, large-scale, dynamic response of ice sheets to climate warming.[14]

Civil Operations and Applications

A major category for applications of Landsat imagery is disaster management. Landsat provides essential data for disaster mitigation and response, and has aided planning and aftermath management for major disasters such as wildfires, floods, tsunamis, droughts, and hurricanes. Approximately 10 percent of USGS data sales—nearly 2000 Landsat scenes annually––are related to disaster planning, assessment, or recovery; the largest application of this data is for wildfire analysis.

National fire trends show that, on average, 3.9 million acres of U.S. lands were burned per year in the four decades between 1960 and 2000; that average has climbed to 6.6 million acres annually for the first half of this decade. To stem the destruction and substantial costs associated with wildland conflagrations, the National Interagency Fire Program has made a long-term commitment to use Landsat-derived maps of fire fuels and other environmental variables to assess fire risk and behavior.

Through the LANDFIRE initiative, Landsat data are being used to generate consistent, comprehensive maps describing vegetation, fire, and fuel characteristics across the United States. These maps are used for prioritizing and planning hazardous fuel reduction and ecosystem restoration efforts. The scale of Landsat coverage assures that data are both locally applicable and useful for national assessments. Figure A-8 is a forest classification product defining canopy

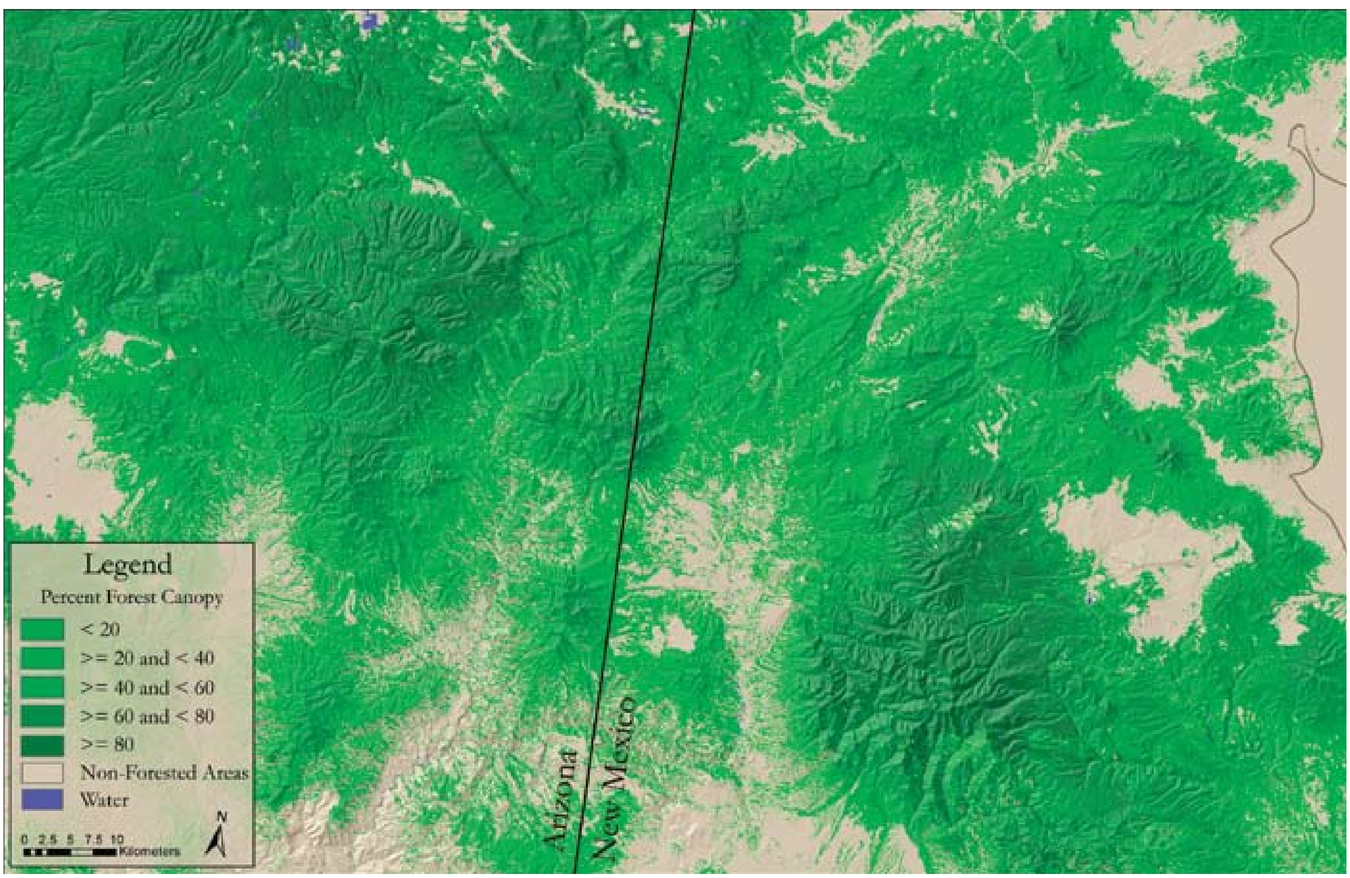

Figure A-8. Percent Canopy Cover for a forested area in Eastern Arizona and Western New Mexico

[14] *H. Jay Zwally et al., "Surface Melt-Induced Acceleration of Greenland Ice-Sheet Flow," Science, 12 July 2002, 297: 218-222.*

density using multi-temporal Landsat imagery.[15] Canopy density is critical to providing forest fuel and fire mitigation analysis.

Landsat data have also been used by the U.S. Forest Service, the USGS, and the National Park Service to produce national burn severity atlases of large wildland fires that have occurred over the past quarter of a century. Burn severity maps quantify the degree of environmental and ecological landscape change caused by fire. These maps support emergency rehabilitation and long-term management of wildlands by providing managers with the information they need to compare the results of different treatments. The spectral and spatial characteristics of Landsat data are well suited for burn severity mapping. Figure A-9 illustrates how different spectral band combinations of Landsat can be used to analyze fire patterns.

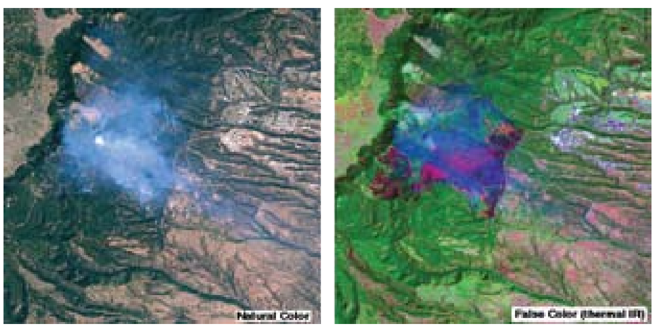

Figure A-9. Landsat 7 imagery of the Cerro Grande fire just outside of Los Alamos, New Mexico

Recently, Landsat data were also used to map coastal change caused by Hurricanes Katrina and Rita, as shown in Figure A-10. In 2005, these catastrophic storms inundated coastal regions along much of the central Gulf Coast. The USGS National Wetlands Research Center used Landsat data to calculate the area of coastal land lost to these storms.[16] These maps now serve as a regional baseline for monitoring wetland recovery following Hurricanes Katrina and Rita.

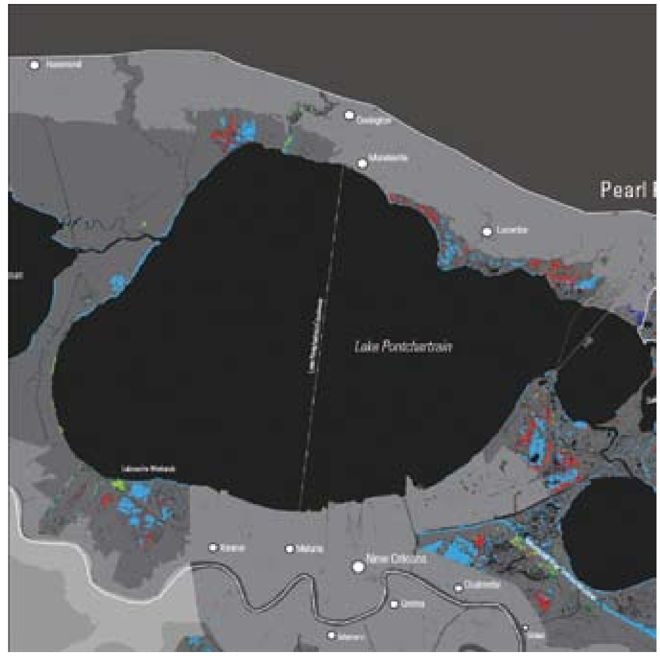

Figure A-10. USGS Map of coastal change using Landsat data. Red areas indicate land loss to Hurricanes Katrina and Rita.

National Security

Whereas the specific applications of Landsat for national security are typically for classified uses and therefore cannot be discussed in this report, Landsat plays a role in U.S. military operations and intelligence gathering. Anecdotal evidence suggests that Landsat greatly improved global surveillance during the 1990 Gulf War and improved tactical management of troops maneuvering in unfamiliar terrain using uncharted regional road networks. An unclassified assessment of the operations and impact of those space operations conducted by the U.S. Space Command and its components stated that: "The military utility of multi-spectral imagery (MSI) was clearly demonstrated during Desert Shield and Desert Storm. Many of the maps that the U.S. forces carried with them of Kuwait City and the area of operations (AO) were made from MSI products. The planning and execution of strike operations were often dependent on MSI data provided by the U.S. commercial LANDSAT spacecraft and its French counterpart, SPOT (Satellite Probatoire d'Observation de la Terre (Exploratory Satellite for Earth

[15] *Haydee M. Hampton, "Spatial Tools for Guiding Forest Restoration and Fuel Reduction Efforts," Proceedings of the 23rd Annual ESRI International User Conference, San Diego, California, 2003.*
[16] *John A Barras, "Land area change in coastal Louisiana after the 2005 hurricanes—a series of three maps," U.S. Geological Survey Open-File Report 06-1274, 2006.*

Observation)).”[17] See the Classified Annex to this report for more details about the value of moderate-resolution land imagery for intelligence uses and other aspects of national security operations.

Treaty and Legal Compliance

Landsat imagery is used to help fight crop insurance fraud (see Figure A-11), preventing millions of dollars in false claims made to the U.S. Government. The USDA Risk Management Agency (RMA) is the primary source of risk protection for American farmers. In its efforts to combat waste, fraud, and abuse in U.S. crop insurance programs, the RMA has been using satellite imagery to monitor the agricultural areas of the conterminous U.S. The RMA uses tools such as Landsat satellite imagery to support farmers’ claims and helped monitor the validity of over $44 billion of protection provided by the crop insurance program to farmers and ranchers in 2005. Ensuring that benefits are distributed equitably among the nearly one million program participants and that taxpayer dollars are safeguarded is a large task for the RMA and for private insurance companies that sell and service crop insurance policies.

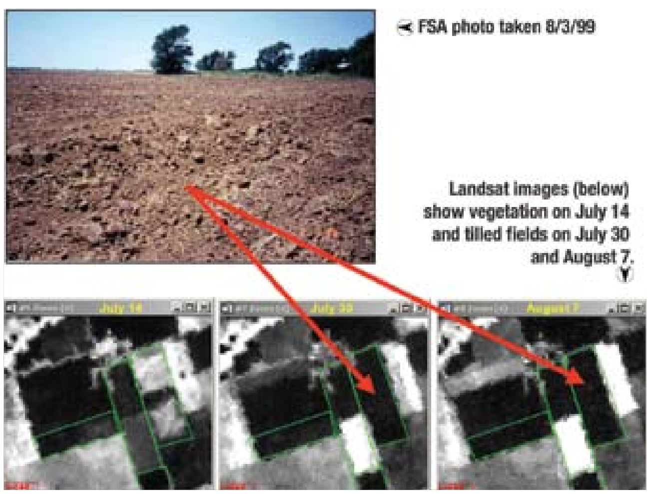

Figure A-11. Landsat used as evidence in crop insurance claims and investigations

[17] *Michael J. Moulo, “Space Handbook: A Warfighter’s Guide to Space,” Air University Press, Maxwell Air Force Base, AL, December 1993, chapter 5.*

The main source of imagery used by the RMA has been Landsat 5 and Landsat 7 satellite data The Landsat series of satellites provide timely data for verification of suspect claims within a growing season and supply a valuable archive of coverage going back to the early 1980s. Over the past three years, the RMA’s use of Landsat data has averaged about 600 scenes per year.

The RMA has used Landsat imagery to support the U.S. Department of Justice in successful civil and criminal prosecution of individuals found to have defrauded the crop insurance program. Landsat data contributed significantly to the conviction and sentencing of 12 individuals who were insurance agents, adjusters, and producers convicted of fraud in 2005. The result of these trials led to over $34 million in restitution or forfeiture, over 400 months of prison time served, and almost 30 years of supervised release. In addition, the publicity gained by the use of satellite imagery for fraud detection is thought to have had a significant deterrent effect in this area.

Catalog of Applications

The following sources identify additional uses of Landsat and other types of moderate-resolution land imaging data:

Commerce and Earth Resource Management:

Precision farming land management (http://landsat.gsfc.nasa.gov/about/Application1.3.html)
Monitoring crop and forest harvests (http://landsat.gsfc.nasa.gov/about/Application1.4.html)
Determining range readiness/biomass/health (http://landsat.gsfc.nasa.gov/about/Application1.5.html)
Characterizing forest range vegetation (http://landsat.gsfc.nasa.gov/about/Application1.9.html)
Monitoring irrigation practices (http://landsat.gsfc.nasa.gov/about/Application1.11.html)
Monitoring lake inventories and health (http://landsat.gsfc.nasa.gov/about/Application4.7.html)
Rainforest vulnerability information (http://landsat.gsfc.nasa.gov/news/news-archive/sci_0005.html)
Water resource management (http://www.kimberly.uidaho.edu/water/metric/index.html)
Commercial fire risk assessment (http://www.sanborn.com/solutions/regional_fire_risk_assesment.htm)
Precision Farming (http://earthobservatory.nasa.gov/Study/PrecisionFarming/)

Environmental Monitoring and Assessment:

Assessing carbon stocks (http://landsat.gsfc.nasa.gov/news/news-archive/sci_0001.html)
Mesoscale atmospheric modeling (http://landsat.gsfc.nasa.gov/news/news-archive/sci_0004.html)
Monitoring ice sheet activity in Antarctica (http://landsat.gsfc.nasa.gov/news/news-archive/sci_0003.html)
Shrinking ponds in Alaska (http://landsat.gsfc.nasa.gov/news/news-archive/sci_0007.html)
Monitoring urban growth (http://landsat.gsfc.nasa.gov/about/Application2.4.html)
Tracking socioeconomic impacts on land use (http://landsat.gsfc.nasa.gov/about/Application2.11.html)
Monitoring deforestation (http://landsat.gsfc.nasa.gov/about/Application6.1.html)
Mapping volcanic surface deposits (http://landsat.gsfc.nasa.gov/about/Application3.5.html)
Measuring changes/extent of glacial features (http://landsat.gsfc.nasa.gov/about/Application4.4.html)
Assessing health of Florida's coral reefs (http://landsat.gsfc.nasa.gov/news/news-archive/soc_0007.html)
Global survey of coral reefs (http://landsat.gsfc.nasa.gov/news/news-archive/news_0031.html)
Rift Valley Fever outbreak risk areas (http://landsat.gsfc.nasa.gov/news/news-archive/soc_0001.html)
Planning for restoration of Chesapeake Bay (http://landsat.gsfc.nasa.gov/news/news-archive/soc_0005.html)
Restoration of Mesopotamian wetlands (http://landsat.gsfc.nasa.gov/news/news-archive/soc_0006.html)
Glacier studies (http://earthobservatory.nasa.gov/Study/GLIMS/)
Irrigation in the Fertile Crescent (http://earthobservatory.nasa.gov/Study/HarranPlains/)
Destruction of Hamoun Oasis (http://earthobservatory.nasa.gov/Study/hamoun/)
Locust destruction (http://earthobservatory.nasa.gov/Study/Locusts/)
Water quality (http://earthobservatory.nasa.gov/Study/WaterQuality/)
Volcanic monitoring (http://earthobservatory.nasa.gov/Study/ReunionIsland/)
Urbanization (http://earthobservatory.nasa.gov/Study/Lights/)
Human impact on Mojave (http://earthobservatory.nasa.gov/Study/Mojave/)

Civil Operations and Applications:

Post-Katrina and Rita land change (http://landsat.gsfc.nasa.gov/news/news-archive/sci_0006.html)
AmericaView (http://www.americaview.org/About.html)
Aiding burned area rehabilitation (http://earthobservatory.nasa.gov/Study/BAER/)
Assessing drought impact (http://landsat.gsfc.nasa.gov/about/Application6.5.html)
Hantavirus risk maps (http://earthobservatory.nasa.gov/Study/Hanta/)
Assessing and monitoring grass/forest fires (http://landsat.gsfc.nasa.gov/about/Application6.7.html)
Mapping floods and flood plain characteristics (http://landsat.gsfc.nasa.gov/about/Application4.2.html)
Determining patterns and extent of turbidity (http://landsat.gsfc.nasa.gov/about/Application5.1.html)
Collaboration for cancer research (http://landsat.gsfc.nasa.gov/news/news-archive/soc_0003.html)

Quantifying burn severity (http://landsat.gsfc.nasa.gov/news/news-archive/soc_0004.html)
Landsat base map for Google Earth™ (http://landsat.gsfc.nasa.gov/news/news-archive/dyk_0002.html)
Land Cover Institute (http://landcover.usgs.gov/)
More lawns than irrigated corn (http://earthobservatory.nasa.gov/Study/Lawn/)
Heat in urban cities (http://earthobservatory.nasa.gov/Study/GreenRoof/)
Mississippi flood (http://earthobservatory.nasa.gov/Study/HighWater/)
Landslides (http://earthobservatory.nasa.gov/Study/Landslide/)
Aftermath of Hurricane Floyd (http://earthobservatory.nasa.gov/Study/FloydSediment/)
Mapping fault zones (http://earthobservatory.nasa.gov/Study/Tectonics/)
Mapping fire extent (http://earthobservatory.nasa.gov/Study/BOREASFire/)

Treaty and Legal Compliance:
Landsat island (http://landsat.gsfc.nasa.gov/news/news-archive/dyk_0001.html)
Landsat helps fight crop insurance fraud (http://landsat.gsfc.nasa.gov/news/news-archive/soc_0002.html)
Mapping support for border compliance (http://www.bic.state.tx.us/index.html)
Moderate resolution imagery and arms control (http://faculty.biu.ac.il/~steing/conflict/athens.htm)
Ecosystem management treaties (http://sedac.ciesin.columbia.edu/rs-treaties/RS&EMTreaties_Nov05_screen.pdf)
Environmental treaties (http://sedac.ciesin.columbia.edu/rs-treaties/index.html)

The Economic Value Proposition of Moderate-resolution Land Imaging

Information used by decision-makers is most valued when either the current situation or the future outlook is “uncertain” or when information is most likely to change prior “beliefs” and the decisions that affect society.

Assessment of the value of information can be carried out qualitatively by econometricians and others; quantifying that value, however, is a challenge. Because information is not normally traded in markets, rigorous valuation of information requires comparisons of the decisions that would have been made with or without the information, and what the consequences of those decisions would have been. One approach to quantifying the *gross* value of improved information involves subtracting the expected value to society of actions taken without the benefit of information versus the value to society of actions taken with the requisite information. Quantifying the *net* value of new information involves subtracting the costs of providing the information from the gross value.[18]

[18] *D.F. Bradford et al., “The value of information for crop forecasting in a market system: Some theoretical issues.” Review of Economic Studies, 44, no. 3 (1977): 519-531.*

Ex-ante studies performed in the early 1970s identified potential benefits of the original Landsat satellite, at that time called the Earth Resources Technological Satellite (ERTS), and the planned “operational” Landsat science program that was expected to develop and contribute to societal decision-making.[19] At that time, the contribution of Landsat to U.S. agriculture alone was estimated to be at least $20 million annually (1973 dollars); much higher benefits were also estimated, depending on which assumptions were made about future improvements in information that would result from the development of Landsat applications.

However, a recent review of those two seminal works showed that these studies neglected to anticipate the substantial difficulties that would affect the implementation of Landsat data use. In many cases, expected applications either never developed or they did not result in expected benefits because Landsat data was not used in the ways that were expected. Often, this was the result of changes in the value of Landsat data compared to other data sources over time. But just as often, the cost of Landsat data, which were priced well above anticipated levels when Landsat was commercialized in 1979, or the natural reticence to change traditional practices led to outcomes that diverged from what was anticipated.

[19] *Robert J. Christie et al., “The Economic Value of ERTS-B,” Report # 74-2002-1, ECON Inc., Princeton, New Jersey, 1974.*

As a result, agriculture and other industries have not realized many of the benefits of Landsat data and more advanced applications have been slow to develop, if at all. Furthermore, since no U.S. office or Federal agency was chartered with the responsibility to develop Landsat applications and promote their use, operational implementation of Landsat uses across Federal, State, and local government either did not occur or never reached the level of application anticipated in the studies done in the early 1970s.

In 1982, the Office of Technology Assessment, a Congressional agency that has since been disbanded, commented on the state of the Landsat program:

> "Although the current Landsat program has been an R&D system designed to verify the potential of satellite remote sensing, through the leadership of NASA, the data from Landsats 1, 2, and 3 have attracted a wide variety of users (resource managers) in this country and abroad. These users consider Landsat data to be an invaluable component of the larger realm of resource inventory data from all sources. For some, data from Landsat have become a baseline requirement of their daily routine. For others, these data serve the secondary, but important role of a comparison data base. Generally, the users treat Landsat as if it were an operational system, even though it is still officially an R&D system managed by NASA.... One of the reasons for the user community's current dissatisfaction with certain aspects of Landsat is that it has remained an R&D system too long."[20]

The Landsat Program succeeded in providing a minimum level of continuous, objective, reliable, global, and accurate land surface data for the world's use despite a confused 35-year history that included being reassigned to several different U.S. agencies, surviving two failed commercialization attempts, and now relying on two satellites that have either exceeded their design lives (by up to 20 years) or suffered serious on-board anomalies that dramatically affect the utility of the data.[21]

[20] *"Civilian Space Policy and Applications," Office of Technology Assessment, National Technical Information Service, Order #PB82-234444, 1982.*

[21] *Kass Green, "Landsat in Context: The Land Remote Sensing Business Model," Photogrammetric Engineering and Remote Sensing, Vol. 72, No. 10 (October 2006), 1147.*

Furthermore, despite the utility of Landsat for scientific, civil government, and national security users, the U.S. failed to adequately provide for the management and sustainment of this program. This led to many U.S. information requirements remaining unfulfilled, as application development in the U.S. Government lagged and commercial re-sellers failed to aggressively develop their markets (mostly to government users) because of the uncertainty of the U.S. commitment to the program. Industries are slow to be, or incapable of being, developed, particularly given the complexities and demands of capital markets, when key systems and technologies are left to be managed on an *ad hoc* basis, or not at all.

> "The fact that we have had a continuous record of Landsat coverage since July 1972 without any gaps in that coverage is more a matter of good luck and excellent engineering than careful management oversight."[22]

Other factors have also impeded the development of applications of Landsat data, including highly priced data products (particularly under the period of Landsat commercialization), commercial licensing restrictions (removed in 1999), and the lack of any U.S. plan for transitioning Landsat from being a scientific satellite to a satellite to be used on a sustained basis for U.S. land-based operations. Accordingly, in verifying and substantiating its work on the uses plus real and potential economic value of moderate-resolution land imaging, the FLI IWG considered survey results gathered by the American Society of Photogrammetry and Remote Sensing (ASPRS) during the summer of 2006 (see Exhibit 9).

In this unscientific sampling, the ASPRS surveyed its members and the members of other remote sensing organizations to evaluate the "estimated value" of moderate-resolution land imaging to users and industries that support those users. The survey found that the economic impact of losing moderate-resolution land imaging would be over $1 billion annually. Furthermore, the survey found that one major group in what is known as the "Landsat community" consists of commercial Value Added Resellers (VARs). The number of VARs has been increasing rapidly due to recent advances in the field.

[22] *Darrel L. Williams, "Landsat: Yesterday, Today, and Tomorrow," Photogrammetric Engineering and Remote Sensing, Vol. 72, No. 10 (October 2006), 1171.*

One anecdotal piece of information from the survey describes the effect that land remote sensing has had on VARs clients: one company's clients include 13 agencies and organizations in the Department of Defense (DOD) and the intelligence community; multiple entities within the (U.S. Department of the Interior) DOI, Department of Commerce, and Department of Agriculture; the U.S. Environmental Protection Agency (EPA); the Federal Emergency Management Agency (FEMA) in the Department of Homeland Security, the National Aeronautics and Space Administration (NASA), and entities in state government and the private sector. The combination of comprehensive coverage at regional to national scales and moderate-resolution is essential to many of the applications, including those shown in Table A-2. Although this company also works with high-resolution data from both defense/intelligence sources and the private sector, company representatives emphasized that those datasets complement, rather than replace, the role of moderate-resolution imagery such as Landsat provides. Recent projects illustrated in the presentation slides included land use change detection on the Gaza-Egypt border and illicit crop inventory (opium poppy cultivation) in one province of Afghanistan. Another recent project compared the areas of the Indian Ocean affected by the December 2004 tsunami with pre-tsunami scenes, to highlight alterations of coastline and underwater hazards.

Table A-2 lists applications of moderate-resolution satellite data provided by VARS to various government agencies.

Table A-2. Moderate-resolution Applications Provided by Value Added Resellers (VARs) ***(provided by ASPRS)***

Civil Agencies	**DOD/Intelligence Community**
Land cover mapping	Change detection
Change detection/monitoring	• Intelligence tip-offs
Disaster response	• Monitoring
Humanitarian relief	• Map updating
Geologic mapping	Illicit crop assessment
Forestry assessment	Food security
Agricultural assessment	Land cover mapping
Wetlands mapping	Shoreline/hazards mapping
Fire risk assessment	Infrastructure mapping
Impervious surface mapping	
Environmental monitoring	

The Value of U.S. Leadership in Land Imaging

Even more difficult to quantify than information—but readily apparent—is the value of U.S. technical and scientific leadership in land imaging and its benefits to society. Well before global climate change science was recognized as a distinct area of inquiry, Landsat enabled the U.S. to demonstrate international leadership in global-scale Earth-systems science.[23] When climate change research first began to appear in the 1980s, it was moderate-resolution land imagery that was used for calibration and "ground-truthing" of data to ensure that climate model research had a foundation in fact, not just theory.

Today, Landsat is the only moderate-resolution satellite monitoring system capable of acquiring seasonal global land surface data that are useful for assessing worldwide land surface and land use changes. The Landsat 7 Long-Term Acquisition Plan (LTAP), the method used to identify the data collection plan for Landsat, was the world's first successful automated global targeting plan for land imaging that observes every land surface area of the Earth multiple times per year. Also, this type of automated land observing strategy not only saved money by more frequently targeting those land surfaces that experienced frequent changes, but it ensured that information about land surface changes would be available for sophisticated techniques in climate and Earth modeling.[24] Once again, the societal benefit of cost savings in research and model advancement cannot be quantified in dollars, but exemplifies how Landsat has provided many indirect benefits to society.

Likewise, many years in advance of the world's recognition of the importance of having a Global Earth Observing System of Systems (GEOSS), the

[23] *Darrel L. Williams, "Landsat: Yesterday, Today, and Tomorrow," Photogrammetric Engineering and Remote Sensing, Vol. 72, No. 10 (October 2006), 1171.*
[24] *Brian Markham et al., "Landsat-7 Long-Term Acquisition Plan Radiometry-Evolution over Time," Photogrammetric Engineering and Remote Sensing, Vol. 72, No. 10 (October 2006), 1129.*

Landsat program established the most extensive international ground-station cooperator network in the world. Today, the Landsat network includes 15 ground stations that are managed through agreements with 11 national and multi-national space agencies. Despite the advanced age of Landsat 5, over 13,500 scenes are still being downloaded from it annually by international partners.[25] The economic value to the U.S. in goodwill, trade exports, contributions to peace, economic development, and security in the world is a "societal benefit" that cannot be quantified in dollars. However, Landsat exemplifies the legacy of the best of U.S. contributions of space technology to the world's benefit by providing leadership for solving Earth resource problems, consistent with the original premise of the 1958 Space Act.

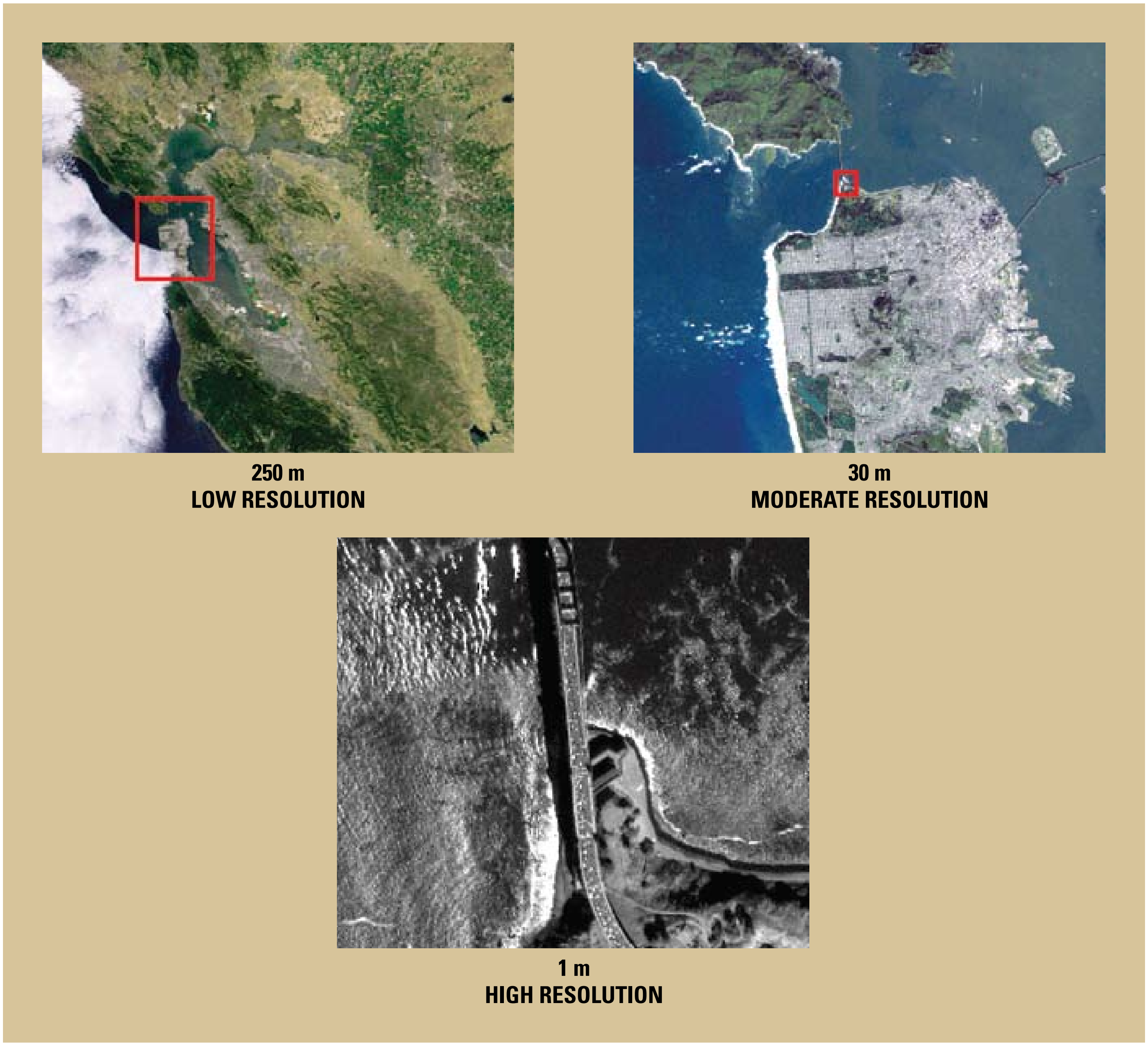

Figure A-12. Central California-San Francisco area: coverage comparison of low-resolution (MODIS), moderate-resolution (Landsat), and high-resolution (IKONOSTM), satellite images. Red box indicates subset of next-higher resolution image.

[25] *Darrel L. Williams, "Landsat: Yesterday, Today, and Tomorrow," Photogrammetric Engineering and Remote Sensing, Vol. 72, No. 10,(October 2006), 1171.*

Appendix B:
Options for Maintaining U.S. Civil Land Imaging Data Availability

Introduction

In developing its plan for achieving stability for U.S. operational land imaging, the Future of Land Imaging Interagency Working Group (FLI IWG) assessed three areas of concern. Why does the U.S. need moderate-resolution land imaging data? What are the technical and programmatic means by which those data would be acquired in a continuous, repeatable manner? How should these data needs be managed?

To address the second of these areas of concern, the means by which future moderate-resolution land imaging data would be continuously acquired, there are four options:

1) a government-owned satellite;
2) a U.S. public-private partnership;
3) an international partnership; and
4) a commercial program.

In keeping with guidance issued by the Office of Science and Technology Policy in December 2005, the FLI IWG focused on these four options for fulfilling U.S. needs for moderate-resolution data. The FLI IWG also remained open to the possibility that the U.S. might rely on some combination of these options.

The FLI IWG did not set out to assess specific spacecraft systems or other technical means by which data would be acquired by the U.S., but focused instead on which option would best assure that U.S. operational needs for land imaging data would be met while meeting other applicable U.S. policy requirements.

Furthermore, the FLI IWG accomplished its work consistent with the goals and objectives of the U.S. Integrated Earth Observation System (IEOS), which is the U.S. contribution to the Global Earth Observation System of Systems (GEOSS). At least two IEOS goals applied directly to the work of the FLI IWG as it developed a plan for U.S. operational land imaging:

- streamline and sustain existing Earth observation systems that are necessary to achieve societal benefits; and
- establish U.S. policies for Earth observations and data management, and continue U.S. policies of open access to observations, encouraging other countries to do likewise.

The following is a discussion of the state of moderate-resolution land imaging in the U.S., specification of the characteristics of moderate-resolution data used to meet U.S. needs up to now, and a discussion of the factors the FLI IWG used to select the best means to ensure future availability of moderate-resolution data for the United States.

The State of Moderate-resolution Land Imaging

The Legacy of Commercial Uses of Space

Since the dawn of the space age, the United States has developed, tested, and flown a wide range of satellite systems designed to study the Earth and provide applications of increasing importance to Earth's societies and economies. The range of space-based observing systems has been wide and diverse; it includes many different types of scientific satellites as well as early prototypes and advanced versions of telecommunications, weather forecasting, and Earth-imaging systems.

In a very brief time, telecommunications satellites became essential tools for a new global society that emerged upon the Earth, linking nations, people, and geographies across intercontinental and global distances unlike any previous technology had accomplished. Early transmission of television signals across those distances led to immediate public acceptance and initial commercial success of this new space technology, a fact mirrored currently by the myriad of advanced telecommunications systems and voice, video, and data applications in which nations around the globe continue to choose to invest.

Experimental weather satellites led to a similar, but less obvious, transformation from research test bed to operational capability. Increasingly sophisticated cloud imaging technologies, augmented by ground-based temperature, atmospheric moisture, and wind speed measures, produced more accurate and specific estimates of severe weather further in advance of its outbreak. Combined with advances in computing technology, weather forecasting became reliable and essential to public safety, so that modern weather alerts and evacuation notices issued by U.S. weather forecast centers lead to immediate response by civil authorities and populations caught in the path of windstorms, hailstorms, tornadoes, snowstorms, and hurricanes.

At present, the products of weather satellites—satellite images of clouds and data about wind speed and direction—are commonplace in every American household and form the backdrop for virtually every weather broadcast televised daily and nightly in America. Many commercially viable businesses throughout America have sprung up around the publication and distribution of weather data and images. In fact, since weather satellites are considered to be so important to public safety, ownership and operation of U.S. weather satellites is restricted to the U.S. Government.[1]

More recently, the U.S. Global Positioning System (GPS) became another successful example of how a U.S. Government-owned and -operated satellite system can spawn a commercial economy, even though the satellite constellation is produced for U.S. Government purposes. GPS signal receivers are now installed in a wide range of consumer products in the U.S. and around the world, including cellular phones, watches, boats, and automobiles. Commercial application of GPS signals is also prevalent in many industrial sectors of the U.S. economy, including the trucking and shipping industries.

Land Imaging Satellite Systems

Land imaging satellites, a specialized class of Earth observation tools whose origins lie in a diverse range of fields, were also considered ripe for commercial development and use since the early years of the space age. High-resolution imaging satellites, whose historic roots lay in aerial photography, have always been considered important for U.S. military surveillance and intelligence operations and are increasingly significant in a number of civil fields, including mapping, urban planning, and disaster management.

[1] *P.L. 102-555 The Land Remote Sensing Policy Act of 1992 restricts the development of U.S. weather satellites to the U.S. Government.*

Similarly, Landsat, the U.S. moderate-resolution land imaging satellite, was also assumed to be highly relevant to U.S. civil operations and thus to the broader economy since its first flight in 1972. From that time forward, the U.S. pioneered civilian land remote sensing from space and has served both U.S. and international science and economic purposes by providing moderate-resolution land imagery to nations and users throughout the world.

Landsat set a standard for international cooperation due to its adoption of an Open Skies remote sensing data policy, including both U.S. and international open access to Landsat data and direct transmission of satellite data to numerous nations around the world as Landsat passes over their territory.[2]

Early in the life of the Landsat program, the Carter Administration decided to commercialize Landsat, a decision that was followed by enactment of P.L. 98-365 Land Remote Sensing Commercialization Act of 1984. This law directed the National Oceanic and Atmospheric Administration (NOAA), the agency assigned to manage Landsat after the satellite was produced by the National Aeronautics and Space Administration (NASA), to migrate the program from the U.S. Federal Government to ownership and operation by U.S. commercial industry.

Despite the expectation that land remote sensing would follow in the footsteps of successful telecommunications satellites, commercial development of moderate-resolution land imaging satellites, including Landsat, has never taken root commercially, either in the U.S. or internationally.[3]

[2] *The Landsat "open access to data" policy has been in effect during both commercial management of Landsat during the 1980s and 1990s and while Landsat has been under U.S. Government ownership and control. For other NASA research data, such as the low-resolution MODIS land imaging data, NASA also adopted a policy of unrestricted distribution of data to users worldwide. These U.S. data policies have set precedents that have influenced the United Nations remote sensing principles and enabled the future Global Earth Observation System of Systems (GEOSS), which is dependent on open access to data among nations, to adopt similar policies for exchange of science and operational information.*

[3] *The French SPOT satellite was also developed with the expectation that the satellite would spawn commercial markets that would pay for future satellite development and launch. However, development of SPOT satellites continued to be underwritten by the French Government throughout this program's history, even though SPOT data is sold commercially throughout the world.*

Public and Private Roles in Land Imaging

Today, both high- and moderate-resolution U.S. land imaging satellites used for civil applications exist only because the U.S. Government has chosen to develop and launch or purchase the data of these satellites at levels sufficient to ensure the satellites will be produced by industry. These satellites include Digital Globe's Quickbird and GeoEye's IKONOS and OrbView systems. Since 2000, the National Geospatial-Intelligence Agency (NGA) has made commitments of approximately $1.5 billion to purchase U.S. and foreign commercial high-resolution satellite data, partly to maintain a viable U.S. commercial remote sensing satellite industry.

Likewise, despite the use of commercial distribution of satellite imagery by many nations throughout the world, including France, Germany, India, and several developing nations, all imaging satellites currently produced throughout the world rely upon direct government funding or indirect subsidies through large government data purchases, etc.

Nonetheless, commercial prospects of U.S. satellite operations firms and foreign government land imaging capabilities have undergone marked development, spurred by heightened public awareness, steady emergence of new applications and markets, and commercial and international competition and cooperation between nations. Just as the science and technology of land imaging has matured beyond the initial science and demonstration projects of the past several decades, so too are new business plans, methods of public-private collaboration, and methods of government-to-government cooperation in land imaging and land science emerging.

Production of high- and moderate-resolution land imaging satellites is rapidly expanding throughout the world, and an increasing number of nations are establishing national plans to develop, launch, and operate land imaging satellites, sometimes with the cooperation of industry partners who agree to distribute these satellite's data commercially and, in some cases, publicly.[4]

Advances in these emerging business and technology trends are such that governments around the world are now exploring greater government-to-government cooperation across the full range of the Earth sciences and related applications, including natural resource conservation and management, energy management, disaster management, and climate and weather research.

An early international entrant was the French SPOT program, followed more recently by India, China, Brazil and smaller developing nations. All these nations have launched or plan to launch moderate-resolution land imaging satellites in upcoming years. Even more active are French, Japanese, German, Indian, Chinese and other national plans to develop and sustain a variety of high-resolution, hyperspectral, and radar imaging satellites.

As a part of its work, the FLI IWG undertook a survey of the world's current and projected moderate-resolution (5- to 120-meter pixel resolution) land remote sensing systems (see Table B-1 below). Though not all of these systems will be operational after the Landsat Data Continuity Mission (LDCM) reaches the end of its projected design life in 2016, there is a definite uptrend in the demand and supply of these types of systems. Table B-1 lists 46 moderate-resolution satellites currently on orbit or projected to be on orbit over the next four years. Of these, four satellites are of U.S. origin and the rest are internationally owned and operated systems.

[4] Private distribution of satellite data is an emerging trend for both high- and moderate-resolution imaging systems throughout the world. However, the governments of Brazil and China recently committed to the free, public distribution of CBERS satellite data. These countervailing trends in imagery and data distribution are currently the focus of discussions among space agencies throughout the world as expectations about the use of satellite imagery to serve public needs and the needs of developing nations are taken into account.

Table B-1. Current and Planned Moderate-resolution Imaging Satellites (by Launch Date)

SATELLITE	COUNTRY	LAUNCH	PAN RES. M	MS RES. M	SWATH KM
Landsat 5	US	03/01/84		**30**	185
SPOT-2	France	01/22/90	**10.0**	20	120
IRS 1C	India	12/28/95	**6.0**	23	70, 142
IRS 1D	India	09/29/97	**6.0**	23	70, 142
SPOT-4	France	03/24/98	**10.0**	20	120
Landsat 7	US	04/15/99	**15.0**	30	185
TERRA (ASTER)	Japan/US	12/15/99		15, 30, 90	60
MTI	US	03/12/00		5, 20	12
EO-1	US	11/21/00	**10.0**	30	37
Proba	ESA	10/22/01	**8.0**	18, 36	14
SPOT-5	France	05/04/02	**2.5**	10	120
DMC AlSat-1 (SSTL)	Algeria	11/28/02		32	600
DMC NigeriaSat-1 (SSTL)	Nigeria	09/27/03		32	600
DMC BilSat (SSTL)	Turkey	09/27/03	**12.0**	26	24, 52
DMC UK (SSTL)	UK	09/27/03		32	600
IRS ResourceSat-1	India	10/17/03	**6.0**	6, 23, 56	24, 140, 740
CBERS-2	China/Brazil	10/21/03	**20.0**	20	113
FormoSat (RocSat2)	Taiwan	04/20/04	**2.0**	8	24
ThaiPhat (SSTL)	Thailand	12/01/04		36	600
MONITOR-E-1	Russia	08/26/05	8.0	20	94, 160
Beijing-1 (SSTL)	China	10/27/05	**4.0**	32	600
TopSat (SSTL)	UK	10/27/05	**2.5**	5	10, 15
ALOS	Japan	01/24/06	**2.5**	10	35, 70
RazakSat*	Malaysia	11/01/06	**2.5**	5	?
VinSat-1 (SSTL)	Vietnam	11/01/06	**4.0**	32	600
Sumbandilasat	South Africa	12/12/06		6.5	45
RapidEye-A	*Germany*	06/01/07		6.5	78
RapidEye-B	*Germany*	06/01/07		6.5	78
RapidEye-C	*Germany*	06/01/07		6.5	78
RapidEye-D	*Germany*	06/01/07		6.5	78
RapidEye-E	*Germany*	06/01/07		6.5	78
CBERS-2B	China/Brazil	06/15/07	**20.0**	20	113
THOES	Thailand	06/30/07	**2.0**	15	22, 90
HJ-1-A	China	07/01/07		30, 100H	720, 50
HJ-1-B	China	07/01/07		30, 150, 300	720
X-Sat	Singapore	04/16/08		10	50
CBERS-3	China/Brazil	05/01/08	**5.0**	20	60, 120
Hi-res Stereo Imaging	China	07/01/08	2.5, 5.0	10	?
Nigeria Sat-2	Nigeria	07/01/08	2.5	5, 32	?
Venus	Israel/France	08/01/08		5.3	28
Alsat-2A	Algeria	12/01/08	**2.5**	10	?
IRS ResourceSat-2	India	12/15/08	**6.0**	6, 23, 56	24, 140, 740
Alsat-2B	Algeria	12/01/09	**2.5**	10	?
CBERS-4	China/Brazil	07/01/10	**5.0**	20	60, 120
SeoSat	Spain	07/01/10	**2.5**	10	?
LDCM	US	07/01/11	**15.0**	30	177

Commercial **Near Equatorial Orbit* *Revised 11/27/06*

Assessing the Need for Moderate-resolution Land Imaging Data

Moderate-resolution land imaging data fill a number of special needs of governments, scientists, and other users throughout the U.S. and the world, and should be considered a high priority for continued U.S. investment among other Earth-observing capabilities.

Moderate-resolution land imaging data are used by a broad range of Federal, State, local, and tribal governments, plus academic, non-profit, and private sector users. Many of these non-profit and private sector users work in concert with or in direct support of governments in meeting societal needs, having a direct bearing on U.S. environmental, economic, and national and homeland security.

Federal users of these data include nearly every Cabinet-level department, including the U.S. Departments of Agriculture, Commerce, Defense, Energy, Homeland Security, Interior, Justice, Transportation, the U.S. Department of State/ Agency for International Development, the U.S. Environmental Protection Agency, NASA, NGA, and the National Science Foundation.

The U.S. has fulfilled its need for moderate-resolution data through the Landsat program ever since the 1972 flight of Landsat 1, or the Earth Resources Technology Satellite as it was then called. Since that time, the Landsat series of satellites has produced the longest continuous and most accurate record of the Earth's land, snow, and ice surfaces available to users in the U.S. and around the world. The resulting 35-year, uninterrupted record of data is considered one of the most important imagery records available to scientists and governments throughout the world, and is of such quality that it can be relied upon to detect real changes on the Earth's surface over time, not subject to the imperfections and artifacts often characteristic of imaging systems of lesser quality. The U.S. has also maintained a commitment to make its archive of global land features available to all U.S. and international public and private users. This commitment includes the willingness to periodically migrate enormous amounts of historical data from obsolete to technologically current storage media so that users can reliably retrieve, process, and compare current and historical land-surface images.

It is because of the importance of this uninterrupted imagery record, and the technological and policy leadership the U.S. has shown in producing it, that selection of future options for fulfilling U.S. operational needs for land imaging is so critical a question. The U.S. has not launched a replacement satellite since the launch of Landsat 7 in 1999, and Landsat 5 (launched in 1984) and Landsat 7 have suffered a series of technical problems that either restrict the satellite coverage of the entire Earth or limit the quality of the satellite data for many users, respectively. Under current projections, both satellites will have reached the end of their fuel lives by the end of 2010 and will need to be decommissioned. Since LDCM will not be launched until 2011 or later, the U.S. anticipates there will a first-ever gap in the Landsat data record. Because Landsat 5 and 7 are not "healthy" satellites, having experienced a number of critical anomalies, this gap could be much longer.

Outside of this report, neither the U.S. commercial sector nor any U.S. Government program has a plan to provide these data beyond LDCM, despite their importance to U.S. operational and research needs. Furthermore, even though production of U.S. moderate-resolution satellites has not resulted in a robust commercial market for satellite imagery, users of Landsat imagery and data derived from that imagery express a need for more—not less—moderate-resolution data, particularly images of the Earth's surface produced on a more frequent basis than once every 8-16 days.[5]

In some ways, these determinations might be considered paradoxical. How can a satellite system that has not generated a robust market for its imagery after 35 years of operation still be considered viable and essential by U.S. imagery data users? The answer lies in the characteristics of the imagery itself. A moderate-resolution satellite such as Landsat is capable of producing imagery that captures detail not seen in low-resolution climate and weather satellite images, and does so on a frequency of global coverage that cannot be achieved by either high-

[5] Landsat's orbital height and frequency are designed to capture large swaths of data at a rate that produces at least one cloud-free data set of the whole Earth each season. As a result, Landsat is designed to revisit every location on the Earth's surface every 16 days. Since there are two Landsat satellites currently in orbit, each location on the Earth can, in theory, be imaged every 8 days; however, Landsat 5 is unable to record or relay images outside the data-reception "footprints" of its ground receiving stations.

resolution aerial or satellite systems and at a level of quality that sets the standard for remotely-sensed land imaging data. For that reason, moderate-resolution systems fill a special "niche" among the family of science and operational data instruments used to image the Earth.

The Future Importance of International Cooperation

Since 2003, the world's nations have gathered for a series of Earth Summits and international meetings to discuss how Earth observation and Earth science can be used to achieve stable, global development and enable better use of satellite and scientific data throughout the world. Applications include disaster mitigation, better weather forecasts, management of oceans, waters, and lands, promotion of human and ecological health, and preservation of Earth's energy resources. The intergovernmental Group on Earth Observations (GEO), headquartered in Geneva, Switzerland, is coordinating efforts around the world to better use science and technology to the world's benefit while advancing the capacity of developing nations to benefit from those advanced systems and technologies.

Under this plan, GEOSS will be used to advance the use of satellite, aerial, and *in situ* observations and archive management resources among the world's nations through sharing of observations and data across national boundaries. The GEOSS architecture is intended to be a broad system of systems capability contributed to by many nations. Consistent with U.S. leadership of this initiative, the U.S. is dedicating many of its satellite and science resources to this effort, including future U.S. land imaging systems. The U.S. formed a parallel U.S. Group on Earth Observations to formulate U.S. needs and identify how U.S. systems and capabilities might be used to serve the broader GEOSS objectives. A strategic plan for IEOS was adopted by the U.S. in 2005 consistent with this strategy.

Defining a U.S. Core Capability in Moderate-resolution Land Imaging

Because Landsat 5 and 7 are expected to no longer be available for Earth imaging prior to the launch of LDCM, the U.S. has been conducting an assessment of the type of moderate-resolution land imaging data required to at least partially meet U.S. needs during the anticipated "data gap" period. The FLI IWG accepted this definition as being the "core capability" of data that should be provided to meet national needs for purposes of its review based on the following considerations. This definition should be refined for future U.S. needs assessments and as future U.S. needs grow.

The core technical capabilities of moderate-resolution land imaging that provide specific contributions to societal benefits are:

- systematic, repetitive coverage of the global land surface;
- synoptic observations of broad areas;
- multispectral observations;
- moderate spatial resolution (30 meters or better); and
- accurate radiometry, geolocation, and cartographic registration.

Each of these characteristics is essential to meeting current U.S. needs for land imaging data and could be improved in the future as new requirements emerge (e.g., a need for hyperspectral or radar data, or data of higher resolution). There are several reasons why these needs should be met.

First, societal benefits are global in extent and repetitive coverage is required to monitor changes and trends of interest to human societies and economies. Imaging that affords at least seasonal global coverage of the land surface is required to maintain continuity with existing Landsat archival records, a benchmark for all moderate-resolution satellites around the world.

Second, observations of the landscape require a wide scope of coverage to be useful for many purposes. The current Landsat satellites, for example, have a field-of-view of 185 kilometers.

Third, multispectral data over the visible, near-infrared, short-wave infrared and thermal infrared are required to characterize the land surface and discriminate between land cover types.

Fourth, moderate-resolution data like those provided by Landsat are currently used to discern the causes and consequences of land surface dynamics and change, resulting in a ground sampling distance (pixel size) of no greater than 30 meters for six multispectral bands, no greater than 15 meters for a single panchromatic band, and no greater than 60 meters for a thermal band.

Fifth, land imaging data should provide accurate, geo-referenced land information. The current Landsat satellite requires knowledge of at-aperture spectral radiance with an uncertainty of less than 5 percent and the registration of pixels to an uncertainty less than 65 meters (90 percent circular error) relative to a standard geodetic reference system.

Additionally, the U.S. land imaging program should also include archival capability to maintain records of land changes over time, and should provide for easy and affordable access to land data.

Table B-2 describes the relevance of the preferred characteristics of a U.S. land imaging system to each of the U.S. GEO societal benefit areas.

Description of the FLI IWG Process

A set of key considerations were developed to guide the FLI IWG analysis. A viable option for meeting U.S. data needs should:

1) ensure that U.S. civil land imaging data needs are met in a reliable and secure manner with objective, unbiased results, particularly when fulfilling sensitive U.S. operational, national, and homeland security requirements;

Table B-2. U.S. Preferred Imaging Characteristics Compared to the U.S. GEO Objectives

Land Imaging Needs for Societal Benefits

Societal Benefits											
Improve Weather Forecasting	Reduce Loss of Life and Property from Disasters	Protect and Monitor Our Ocean Resources	Understand, Assess, Predict, Mitigate, and Adapt to Climate Variability and Change	Support Sustainable Agriculture and Forestry, and Combat Land Degradation	Understand the effect of environmental Factors on Human Health and Well-Being	Develop the Capacity to Make Ecological Forecasts	Monitor and Manage Water Resources	Monitor and Manage Energy Resources	National and Homeland Security	Global Change Science	Observational Capability for Land Imaging
Critical	Critical	No or low need	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Systematic Coverage of Global Land Surface
Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Synoptic Observations - Wide Swath
Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Multispectral Observations
No or low need	Critical	Moderate	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Medium Spatial Resolution
Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Accurate Radiometry and Geolocation
No or low need	Moderate	Critical	Critical	Critical	Critical	Critical	Moderate	Critical	Critical	Critical	Data Preservation and Archival
Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	Critical	No or low need	Critical	Affordable, Publicly Accessible Data

Legend: Critical Requirement; Moderate Requirement; No or low need

Appendix B

2) ensure that U.S. technologies in land imaging continue to be advanced across a wide array of potential systems and capabilities;[6]
3) maintain U.S. industrial capacity in civil land imaging and the ability of U.S. industry to compete for expanding worldwide markets in land imaging and land imaging science; and
4) enable U.S. science, technology, and policy leadership in global Earth observing.

These considerations were translated into a series of questions, or criteria, used to assess each of the data acquisition options. The FLI IWG used these questions to analyze each option, compare the results, and formulate recommendations.

Assessment Criteria

The group derived a set of criteria to choose among these options:

1) Does the option satisfy the operational requirements of U.S. Government users?
2) Does the option conform to:
   a) U.S. national and homeland security interests, and
   b) U.S. foreign policy interests?
3) Does the option ensure that U.S. commercial interests in land imaging, satellite manufacturing, and data distribution and utilization are satisfied?
4) Does the option ensure that land imaging data will be:
   a) available to the U.S. Government on a reliable basis;
   b) unrestricted for all U.S. civil, national security, commercial, and international users as well as for the general public; and
   c) produced and distributed at low cost to all users?
5) Does the option satisfy the requirements of the U.S. Integrated Earth Observation System and U.S. global change research objectives?
6) Does the option provide the best value to the U.S. Government?

[6] *While the initial FLI IWG interest is in acquiring moderate-resolution, optical "Landsat-like" data, broader U.S. Government land imaging requirements could lead toward U.S. or international government and commercial sources for high-resolution optical applications, synthetic aperture radar, LIDAR, or hyperspectral data that could prove beneficial to U.S. operational users.*

Detailed Examination of the Options

Government-Owned Satellite

In this option, the U.S. Government acquires a satellite managed and controlled by the U.S. Government. The U.S. Government also maintains a U.S. archive and distribution capability and assumes responsibility for meeting the data distribution and non-discriminatory data access and availability provisions of Public Law 102-555, the Land Remote Sensing Policy Act of 1992.

This option enables the U.S. Government to ensure that U.S. satellite design and manufacturing capabilities are retained. This option places a premium on ease of access and low-cost use of imagery data by U.S. Government, scientific, non-profit and commercial users, and the U.S. general public.

Per existing U.S. law, data are also provided on a comparable basis to international users, including international governments and non-governmental organizations, foreign commercial firms, and foreign national users. The U.S. is free to enter into binding agreements of any form with international governments and foreign commercial firms since the U.S. retains ownership and control of the satellite system. Tasking and control of the satellite system are exercised by the U.S. Government. Under this scenario, all land imagery obtained by the U.S. Government satellite and processed to a common unenhanced data format (defined as terrain-corrected data per U.S. law) exists in the public domain.

Ownership of satellites by the U.S. Government comes at considerable cost. The U.S. Government is obligated to pay all costs of design, development, launch, and operation of satellite systems and ground systems, except those operational costs borne by a commercial distributor if one is selected. Production of commercial products is managed by commercial firms, both foreign and national. Delivery of services by and for government users and beneficiaries falls under the control and jurisdiction of each Federal, State, and local government that uses moderate-resolution imagery and products. Use of commercial services by government users is encouraged by existing U.S. law and executive policy.

Long-term continuity of the satellite system is also borne by the U.S. Government, including investment in future land imaging technologies that may enhance operational uses of land imaging data. Technology advancement and long-lead procurement of satellite systems using government Research and Development funding is required to maintain this publicly-owned operational satellite system.

U.S. Public-Private Partnership

In this option, the U.S. Government shares roles and responsibilities for satellite acquisition, launch, and operation with U.S. private sector firms. The division of responsibilities between the U.S. Government and commercial industry can be structured in many ways, and can rely on up-front U.S. investment in satellite systems and technology or a future "data-buy" acquisition. Under either scenario, the U.S. Government's financial obligation should not exceed the proportionate value of data provided to the U.S. Government versus the expected value of commercial revenues for data sales.

The U.S. Government retains possession and control of all unenhanced moderate-resolution satellite imagery produced up to terrain-corrected products. Data licensing restrictions are subject to negotiation, but the U.S. maintains its obligation under P.L. 102-555 to ensure ease of access and low-cost use of terrain-corrected imagery by all public and private users, including international users. The private sector partner retains commercial rights to all other data and products, including distribution of those data and products to all U.S. private and public markets. Because of existing U.S. law and long-standing U.S. practices, international governments who acquire the satellite's data using direct-downlink capabilities may retain all rights of local distribution of the satellite's data and derived products for foreign and foreign commercial users.

Satellite design and acquisition costs are either borne by the U.S. Government or by the private sector partner, and either expensed by the U.S. Government, recovered through U.S. "data sales,"[7] or amortized against U.S. commercial sales. International fees for direct access to the satellite's data offset either the government's or the private sector partner's costs.

Acquisition, operation, and control of the satellite, including satellite tasking, is either retained by the U.S. Government or transferred to the private sector partner. Likewise, investment costs required to sustain long-term continuity of U.S. operational land imaging data are either borne by the U.S. Government or the private sector partner, including investment in new technologies and long-lead procurement items. Therefore, long-term, sustained commitment by private lenders *in perpetuam* or by such means as a surety bond should be required to ensure that future U.S. Government obligations to produce satellite systems for U.S. purposes will be addressed.

For purposes of discussion, it should be assumed that the satellite system exists partly in the public and partly in the private domain, subject to terms and conditions of the agreement. The private sector partner should expect that the U.S. Government will honor its obligation to ensure commercial access to U.S. public and private markets in exchange for its investments. This option does not prohibit the U.S. Government from maintaining an archival record of U.S. land imaging data to meet U.S. long-term data access and distribution requirements.

Whereas this option conforms to U.S. national security and U.S. commercial satellite interests, the option does not ensure that future U.S. long-term continuity needs will be met nor that they can be met inexpensively. Deferment of U.S. obligations does not ensure that future costs for data will not be excessive and extraordinary means may be required to ensure long-term continuity of U.S. systems and data. While this option does not preclude that U.S. user needs can be met, it does not provide the U.S. Government with full access to the range of means necessary to do so. Also, this option may make it more difficult for the U.S. Government to address its foreign policy interests in future years, in particular the requirements associated with GEOSS.

U.S. Government attempts to form public-private partnerships with U.S. industry are the norm, not the exception, in moderate-resolution land imaging. From 1985 through 2001, and again in 2003, the U.S. Government attempted to "commercialize" Landsat through structured agreements that relied on U.S. industry to fund future satellite acquisition costs. In 1985, EOSAT was formed as a joint venture of Hughes Aircraft Company and RCA

[7] *Note that this provision is precluded by existing U.S. law and regulation, which specifies that the U.S. Government cannot collect more than the "cost of fulfilling user requests."*

Corporation under contract to NOAA, to build and operate Landsat 6 and exclusively market and distribute imagery and data from Landsat 4, 5, and 6. EOSAT also retained all rights to sales of data to international ground stations worldwide. At the time, the U.S. Government agreed to continue to bear all operating costs of the satellites, and also assumed responsibility to fund development of Landsat 6 by EOSAT. Future commercial Landsat satellites were to be built at EOSAT's expense. This plan led to steep increases in the cost of Landsat imagery for all users, with dramatic impact to government, science, and academic users of the data. In a recent survey of Landsat data users, the high cost of this data and the inability of product developers to rely on future government commitments to Landsat were the main reasons given for the failure of commercial development of the satellite system.

In 1992, the U.S. rescinded this plan and initiated conventional government procurement of Landsat 7. The U.S. also adopted P.L.102-555, The Land Remote Sensing Policy Act of 1992, which imposed new controls over the distribution and future sale of U.S. land imaging data.

After yet another failed attempt in 2003 to commercialize Landsat, as was required by law, the U.S. Government chose to end these efforts and move towards a more conventional development and acquisition approach to ensure future continuity of U.S. land imaging data. As a result, the LDCM is currently under development by NASA and will be owned and operated by the U.S. Department of the Interior (DOI) after its launch. The DOI intends to honor all existing provisions of law pertaining to the acquisition and sale of U.S. land imaging data and products, including assurance of easy access and low cost of this data.

International Partnership

With this option, the U.S. Government would acquire global data from land imaging satellites owned and operated by a foreign partner or a U.S. intermediary for a foreign government or commercial partner. At minimum, the U.S. Government would only be required to maintain U.S. archive and data distribution capabilities necessary to meet existing U.S. law, including the assurance of access and low cost use of imagery data to U.S. Government users. Existing law requiring distribution to other U.S. Government and commercial users would be subject to the interpretation of foreign licensing that may be invoked by foreign sources, and distribution of data to international users of U.S. archival data could be restricted.

If this option were invoked and the U.S. did not produce any moderate-resolution land imaging satellites, this approach would result in total reliance on foreign sources of data, little or no control over the quality and format of that data, and possible restrictions on the use or redistribution of the data. If foreign governments and commercial sources chose to produce land imaging satellites that produce data of lesser quality than existing U.S. data archives, U.S. operations and global land and climate research could be affected. The U.S. may or may not possess the capabilities required to directly acquire and process foreign satellite data, depending on how foreign governments and firms would choose to operate. U.S. responsibilities to the U.S. aerospace industry and to meeting U.S. national and homeland security requirements would have lesser priority.

Different scenarios under this option would result if the U.S. chose to produce either a government-owned or commercial satellite in combination with using international sources of data, or if the U.S. chose to collaborate with international partners by sharing land imaging instruments with foreign suppliers. These scenarios would result in the U.S. retaining control of its own satellite's data or of instrument data provided by a U.S. instrument installed on a foreign satellite. But these scenarios also result in increasing levels of dependence on the projects, objectives, and business success of foreign-owned satellites, particularly if no U.S. satellite is produced. Creation of a U.S.-foreign commercial consortium is yet another alternative, a scenario that would introduce both the risks and the benefits of relying on a U.S. commercial source and a foreign source.

The establishment of "virtual constellations of systems," an idea that is under discussion by the international Committee on Earth Observation Satellites (CEOS), is a variation of this option. This scenario implies that the U.S. and other nations would produce their own satellite systems and collaborate in some way. Methods of collaboration could include simple data exchanges, direct data broadcast of satellite data to all nations, provisions for creating archival "replicas" or "virtual archives" to serve many nations, satellite instrument exchanges, or even international satellite and instrument design to a common set of standards. Direct command and control of satellites across national boundaries might also be considered, but would introduce significant satellite health and safety risks that could interfere with securing other U.S. objectives.

Note that, in general, satellite control and data policies for future systems are still in a period of formulation by most of the nations who plan to deploy future high- and moderate-resolution land imaging satellites, particularly the expectation by many nations that imaging satellites should be operated commercially. Attempts to collaborate across international boundaries will necessarily have to address these national technical and business objectives while also seeking to address the expectations of the international GEO.

Of the foreign moderate-resolution satellites that are currently in orbit, two have been under close review by a multi-agency Landsat Data Gap Study Team chaired by the USGS and NASA. Because of a likely gap in U.S. Landsat data that is expected to occur toward the end of this decade, the U.S. has been examining alternatives to fill in this coverage until the new LDCM is launched in 2011. While there is no current or proposed replacement for Landsat beyond LDCM, India's ResourceSat and the China-Brazil Earth Resources Satellite (CBERS) and possibly others that are still under review might be good sources of useful, but less than optimal, data to substitute for the loss of Landsat data during this period.

For purposes of further assessing foreign capabilities for U.S. use, the FLI IWG established the following technical and policy criteria for evaluating the potential use of foreign satellites and their data under future U.S.-international partnerships, both during and after the upcoming data gap:

1) Do the foreign data meet operational requirements of U.S. Government agencies and other U.S. users?
2) Will the foreign data be readily available without user restrictions, and at little or no cost to U.S. Government agencies and other U.S. users?
3) Are the foreign data of value to the U.S. National Satellite Land Remote Sensing Data Archive and compatible with its historical holdings in terms of data characteristics[8] and quality?
    a) Can the foreign system provide routine global coverage to the U.S. archive?
    b) Can the foreign system provide routine U.S. coverage to the U.S. archive?
4) Can the foreign data and/or sensor be calibrated or validated according to international standards?

For the long term, there are many international systems that might be candidates for augmenting an operational U.S. core capability, filling in data gaps, or providing "niche" data of use to some U.S. decision-makers and analysts, or performing some other role in connection with the international GEOSS being developed in connection with GEO. These international candidates include government-owned and -operated satellites and foreign commercial satellites underwritten or developed by sponsor governments.

Commercial Program

In this option, the U.S. acquires all data from private sources, potentially either or both U.S. and foreign commercial data providers. The U.S. does not retain any rights to land imaging data except those expressed in licensing agreements with the commercial firms. This approach effectively abandons U.S. implementation of the access and low-cost provisions of existing law, and places the U.S. Government and all other U.S. users in a position of being dependent on these commercial sources and their licensing and cost provisions. The U.S. may choose to continue to maintain a U.S. archive of land imaging data, but distribution of those data would also be subject to licensing provisions and the cost of acquiring archive data would be dependent on industry pricing.

At minimum, the U.S. Government may choose to establish a single U.S. agency to "broker" or acquire data for the U.S.; alternatively, the U.S. may choose

[8] Among other considerations, foreign moderate-resolution data must be radiometrically and geolocationally correct, must be capable of being used to produce at least two cloud-free global data sets per year of the entire Earth, and should include near- and short-wave infrared (NIR and SWIR) data to be compatible with U.S. scientific and operational needs.

to disband any centralized agency functions and allow each U.S. agency and all U.S. users (including State and local government, university researchers, and non-profit entities) to acquire their data on the commercial market.

U.S. responsibilities to the U.S. aerospace industry and to U.S. security interests are maintained if land imaging data are acquired from a U.S. commercial firm, but the U.S. Government would lose some flexibility and control over ensuring that U.S. land imaging needs are met.

All costs and investment risks are borne solely by the commercial operator, but the continuity of U.S. land imaging data and satellite sources of data, including long-lead investment in advanced technologies, are at risk to U.S. or international market conditions.

As described above, the previous U.S. attempts to commercialize Landsat were structured as U.S. public-private partnerships designed to transition to fully commercial agreements over the long term. Both existing U.S. law and the 2003 U.S. Commercial Remote Sensing Space Policy encourage the use of commercial sources to fulfill U.S. data needs. However, since previous attempts to privatize, then commercialize Landsat did not succeed, the FLI IWG concluded that there is no reason to believe that market conditions for moderate-resolution data and satellites have changed.

Selecting the Best Option to Ensure that U.S. Data Needs are Met

A U.S. developed and operated satellite system provides the best means for meeting all of the selection criteria while also ensuring access to affordable land imaging data by all U.S. users. A U.S. owned satellite system best conforms to the needs of the U.S. IEOS initiative, and does not conflict with U.S. interests to promote the commercial distribution and use of land imaging data. The FLI IWG recommends that a reliable U.S. land imaging core capability should be maintained as a continuous on-orbit satellite system.

Continuing U.S. science, technology, and policy leadership in Earth observation requires that the U.S. sustain a robust moderate-resolution land imaging satellite technology. Such leadership requires U.S. commitment to the LDCM, the U.S. contribution to GEOSS, and follow-on capabilities that would be produced by a U.S. Government operational land imaging program.

Other options also met one or more of the above criteria, but no other option was capable of meeting every criterion, either because the option did not ensure that U.S. civil, security, and foreign policy interests or U.S. commercial interests in remote sensing could be met (in the case of solely relying on international sources of land imaging data), or did not ensure that U.S. government needs for land imaging data would be reliably and affordably met (in the case of U.S. commercial and industry partnership options).

However, future U.S. needs for land imaging data can be expected to grow in sophistication and in demand for more frequent data. U.S. demand for operational land imaging data already exceeds the capabilities that can be met by the current Landsat satellites or future LDCM. Many U.S. users would benefit from global land coverage as frequent as every 2-4 days, particularly for time-sensitive uses in agriculture, disaster management, and national and homeland security operations; and the need to meet existing and emerging U.S. requirements for radar, hyperspectral, lidar and other imaging technologies can be expected in coming years.

Yet expanding the range of operational satellite capabilities available to U.S. users and increasing the number of satellites that are deployed may not be affordable or necessary, since over the next few years many different nations may deploy comparable—though in most cases less capable—land imaging systems.

Therefore*, the U.S. operational land imaging program should rely upon U.S. commercial sources and international government and commercial sources to provide capabilities beyond those acquired by the U.S. Government to enhance fulfillment of U.S. operational data needs.* As U.S. demand for high-resolution land imagery expands, consistent with many current market forecasts, U.S. commercial interests may choose to enter the moderate-resolution land imaging satellite market despite past obstacles. Acquisition of moderate-resolution data from U.S. commercial sources would take place as data purchases, with capital expenses either partly subsidized or fully capitalized by commercial investors. Similarly, acquisition of data from international commercial sources could be used to supplement data acquired from either U.S. Government or U.S. commercially owned satellites.

Data could also be acquired directly from international governments. Government-to-government data exchanges could take many forms: operational exchanges of raw or processed data between U.S. and international land imagery archives; international telemetry downlinks from U.S. land imaging satellites and vice versa; international sensors flown on operational U.S. satellites and vice versa; data purchases through an intermediary commercial source; or a virtual constellation of U.S. and international satellites. Both commercial and international government relationships can be used to enhance U.S. ability to meet needs for greater temporal coverage or to provide capabilities that the U.S. chooses not to develop.

Table B-3 shows the results of the detailed assessment conducted by the FLI IWG of the best option to meet future U.S. land imaging needs.

Table B-3. Selecting the Best Option to Ensure that Future Long-term U.S. Land Imaging Needs are Met

Selection Criteria									
Does the option satisfy the operational requirements of U.S. government users?	Does the option conform to U.S. national and homeland security interests?	Does the option conform to U.S. foreign policy interests?	Does the option ensure that U.S. land imaging data commercial interests and utilization are satisfied?	Does the option ensure that land imaging data will be available to the U.S. Government on a reliable basis?	Does the option ensure that land imaging data will be unrestricted for all U.S. civil, national security, commercial, and international users as well as for the general public?	Does the option ensure that land imaging data will be produced and distributed at low cost to all users?	Does the option satisfy the requirements of the U.S. Integrated Earth Observation System and U.S. global change research objectives?	Does this option provide the best value to the U.S. Government?	Option
Meets	Meets	Meets	Meets	Meets	Meets	Meets	Meets	Partially Meets	Government-Owned Satellite
Partially Meets	Meets	Partially Meets	Meets	Partially Meets	Partially Meets	Partially Meets	Partially Meets	Partially Meets	U.S. Public-Private Partnership
Fails to Meet	Fails to Meet	Meets	Fails to Meet	Fails to Meet	Fails to Meet	Partially Meets	Fails to Meet	Partially Meets	International Partnership
Partially Meets	Meets	Partially Meets	Meets	Partially Meets	Fails to Meet	Fails to Meet	Partially Meets	Partially Meets	Commercial Program

Legend:
- Meets
- Partially Meets
- Fails to Meet

Summary and Conclusion

The Future of Land Imaging Interagency Working Group considered four options for fulfilling future long-term needs for moderate-resolution land imaging data: 1) a government-owned satellite, 2) a U.S. public-private partnership, 3) an international partnership, and 4) a commercial program. The group also considered combinations of these options.

The working group was guided by the importance of best assuring that U.S. operational needs for land imaging data would be met while meeting other applicable U.S. policy requirements, including the goals and objectives of the U.S. Integrated Earth Observation System.

The working group recommends that the U.S. Government establish and maintain a core operational capability to collect moderate-resolution land imagery through the procurement and launch of a series of U.S.-owned satellites. In addition, the group recommends that the core operational capability owned by the U.S. be complemented and supplemented through commercial data purchases from U.S. sources, and through international government and commercial relationships, including partnerships, collaborations, data exchanges, and data purchases, as available and appropriate.

Appendix C
Governance of the Future of U.S. Land Imaging

Introduction

The Future of Land Imaging Interagency Working Group (FLI IWG) reached a set of governance recommendations that were selected to ensure managerial stability in meeting the Nation's future civil, operational, moderate-resolution land imaging (hereinafter "land imaging") needs. Governance options were examined against performance criteria that a governance body or system must meet while also supporting the broader goals of:

- assuring the long-term continuity of and/or compatibility with the Landsat data record (defined as a 30-meter spatial resolution, multispectral data set of high radiometric quality);
- providing the Nation with the best scientific and technological options for future land imaging; and
- ensuring that the best means of meeting the Nation's land data needs are being used, including the best strategies for ensuring availability, access, and ease of use of land imaging data for the Nation.

Objectives

The FLI IWG examined all governance scenarios that were considered plausible and realistic using a set of criteria predefined by the FLI IWG and found to be consistent with various technical options for future land imaging, because it was determined that the best governance model is one that provides the greatest degree of flexibility. Likewise, the preferred governance model selected also provides the most effective management and funding strategies while reducing management and implementation risk and providing the highest degree of stability and continuity of future U.S. land imaging operations. The governance options considered for management and operation of a U.S. land imaging program included:

- **single agency -** a single Federal agency would be responsible for all aspects of moderate-resolution land imaging;
- **multiple agencies -** two or more Federal agencies would share responsibility forall aspects of moderate-resolution land imaging;
- **Integrated Program Office (IPO) -** an IPO reporting to multiple Federal agencies would be responsible for all aspects of moderate-resolution land imaging;
- **U.S. National Commission -** a U.S. National Commission, consisting of both Federal and non-Federal members, would manage the U.S. land imaging program, assigning responsibility for various aspects of the moderate-resolution land imaging program to key agencies or institutions; and
- **no U.S. Government manager -** the U.S. would acquire all moderate-resolution land imaging data from commercial or international sources. No U.S. Federal agency would be assigned responsibility for U.S. land imaging.

The governance options listed above were assessed by comparing how they met the predefined set of criteria for each method that could be used by the U.S. to acquire future land imaging data. As described in Appendix B, these methods include a:

- U.S. Government-owned system;
- U.S public-private partnership;
- U.S.-international partnership(s);
- U.S. commercial program; and
- a combination of the above options.

The thorough examination of governance options and data sources created approximately 20 different governance scenarios for examination. These scenarios were evaluated using the following criteria:

- alignment with U.S. scientific, operational, security, and foreign policies and interests;
- financial and budgetary stability;
- flexibility to acquire future data from the best available sources;
- improved accountability to users;
- minimized management complexity;
- operational and managerial leadership in the U.S. and international communities;
- provision of clear and consistent U.S. agency roles and responsibilities; and
- streamlined acquisition and low cost management of data.

To evaluate the governance options, sources, and criteria, the FLI IWG relied heavily on the expertise of its members, who represent the policy perspectives and interests of their respective government agencies, and on the inputs from the U.S. land imaging data user community. The FLI IWG also gave significant consideration to existing reports, studies, policy documents, and views regarding the United States' need for land imaging capabilities. In addition, the FLI IWG examined lessons learned from the *ad hoc* governance models used in the Landsat Program's 35-year history.

Of the approximately 20 governance scenarios considered, five surfaced as the most favorable models, justifying further consideration:

- government-owned/single agency;
- government-owned/multiple agencies;
- public-private partnerships/single agency;
- international partnerships/single agency; and
- commercial program/single agency.

Selection of the "Single Agency" Governance Model

In a unanimous judgment, the FLI IWG selected the "government-owned/single agency" governance model as the option that best met the specified criteria, posed the least amount of risk and offered the greatest degree of flexibility to the U.S. Government with respect to data continuity and program risk, and, in most cases, provided the best alignment with current space-related laws and policies. This judgment resonated with recommendations from both the user community and the U.S. Government agencies involved in the FLI IWG process.

Justification

The Single Agency governance model ranked most favorably overall because of positive evaluations against the evaluation criteria discussed above.

The FLI IWG gave a very high priority to minimizing management complexity and bureaucratic hurdles associated with multiple or integrated agency governance models. In addition, the Group noted the importance of having a single U.S. voice speak on behalf of U.S. land imaging and represent its goals and interests. These benefits were judged to have been lacking in the past and to be the most important to establish.

The only governance criterion where this model was less favorably ranked was "scientific, technical, and managerial leadership," since it was recognized that multiple U.S. Government agencies would be able to provide specialized expertise related to their particular uses of land imaging data. To reflect and capture this single advantage of the "multiple agency" governance model, the Group discussed how a single agency could conduct a U.S. land imaging program in accord with government, commercial, and international users, while also formally acknowledging the role of other U.S. Government agencies. Such roles could include sponsoring the development of advanced land remote sensing systems and technologies (i.e., the National Aeronautics and Space Administration), or representing key stakeholder purposes and applications, roles, and constituencies (e.g., the U.S. Department of Agriculture, the U.S. Department of Defense, or the National Oceanic and Atmospheric Administration).

It was determined that the best Single Agency model is one that gives full recognition of each participating agency's role and set of constituencies, including full recognition of the data and operational system needs that exist throughout the U.S. and across the jurisdictional boundaries of the various agencies of the U.S. Government.

The mission for the lead Single Agency would include effective management designed to best satisfy the U.S. Government's needs across the full range of land imaging capabilities. The Single Agency would also have responsibility for user requirements coordination and integration, system acquisition and operations, data acquisition and archiving, developing new methodologies for data distribution to the widest range of users, and management of a comprehensive program of land management research and applications. The latter responsibility would especially be intended to demonstrate promising future technologies and applications across the broad spectrum of land imagery uses.

Selection and Justification of the U.S. Department of Interior as Lead Agency

In the judgment of the FLI IWG and the stakeholder agencies it represents, the U.S. Department of the Interior (DOI) is the most appropriate U.S. agency to fulfill this Single Agency role. This recommendation is based on:

- the extensive history of the DOI in proposing early U.S. efforts to design, build, and deploy a U.S. land imaging satellite system (the Earth Resources Technology Satellite in 1972, later called Landsat 1), more recently operating the Landsat series of satellites, and maintaining the current U.S. National Satellite Land Remote Sensing Data Archive, which contains the Nation's historic satellite imagery of the Earth's land surface;
- the responsibilities assigned to the DOI under the 1992 Land Remote Sensing Policy Act and the subsequent National Science and Technology Council (NSTC-3) memorandum designating the DOI as the Program Manager of Landsat alongside the National Aeronautics and Space Administration (NASA);
- the 2006 National Space Policy, which assigns to DOI the responsibility to "…collect, archive, process, and distribute land surface data to the United States Government and other users and determine operational requirements for land surface data;" this is supplemented by the 2003 U.S. Commercial Remote Sensing Space Policy under which DOI gathers near-term civil government requirements for U.S. commercial remote sensing data;
- the responsibilities assigned to the DOI for managing the territorial interests of the U.S., overseeing U.S. land management and land use planning, and managing the civil geospatial programs and interests of the U.S., including aerial and satellite land imaging systems and technology, as derived from the DOI and USGS Organic Acts of 1849 and 1879, respectively;
- the DOI's extensive history of conducting Earth science, land management, imagery data distribution, and remote sensing applications development and providing intra- and intergovernmental services to users who have responsibility for conducting science related to geology, morphology, and ecology of the Earth's land surface; and
- the commitment expressed in a memorandum from the DOI to the Office of Science and Technology Policy on May 2, 2006, stating that the DOI is "…ready to accept the challenge of this new century and assume leadership for the Nation's civilian operational land imaging program." The message contained in this memorandum was accepted and endorsed by all the FLI IWG participating agencies and conforms with the views of the national and international Landsat user community.

National Land Imaging Program Leadership

The Group further recommends that a Future of Land Imaging program office—henceforth known as National Land Imaging Program (NLIP)—be established under the DOI and be responsible for all NLIP funding. Agencies participating in the implementation of the NLIP would do so in coordination with the leadership of the DOI NLIP.

The NLIP should establish the appropriate working relationships with other U.S. Federal agencies that are users of U.S. land imaging data, as well as U.S. State, local, and tribal governments, scientific and academic users, commercial users, and international users of land imaging data. The NLIP should endeavor to strengthen the integrity, intent, and implementation of relevant land imaging (remote sensing) polices and laws, including but not limited to: the commercial licensing provisions of the 1992 Land Remote Sensing Policy Act (Title 15, USC, Chapter 82); the Licensing of Private Land Remote-Sensing Space Systems (15 CFR Part 960); the 2003 U.S. Commercial Remote Sensing Space Policy; and 2006 National Space Policy. NLIP should make every effort to not countermand or otherwise restrict the authorities that have been defined (such as with the commercial remote sensing sector) by existing policy and law. In its land imaging leadership role, NLIP should focus on shaping positive outcomes for all U.S. land imaging activities, especially in areas where multiple levels of policy leadership already exist. Since the NLIP concept was not envisioned as a land imaging entity when these policies and laws were developed, it will be necessary for NLIP to demonstrate exceptional leadership in its service to other U.S. agencies and to the U.S. Government.

As the lead Program and advocate for the development of future U.S. land imaging systems and/or for the acquisition of land imagery data for operational purposes, the NLIP should work closely with appropriate U.S. agencies to manage relevant interagency and intergovernmental, commercial, and international agreements for access to land imaging technology or data to be used primarily for civil applications on behalf of the U.S. Government. This responsibility would include strengthening relations with U.S. and international developers and manufacturers of satellite and other remote sensing systems and technologies and with U.S. and international sources of land imaging data, including U.S. commercial satellite operators, international space agencies, and other international sources. The NLIP should ensure that the process for developing future U.S. operational sensors will allow for the rapid infusion of new satellite observational technologies developed from NASA research. Under the NLIP scenario, NASA would work with DOI and the National Oceania and Atmospheric Administration (NOAA) to transition leading edge, science-based sensor systems into operational land (DOI) and ocean and atmospheric (NOAA) sensors.

U.S. agencies that acquire satellites, systems, or data for uses other than land imaging, land science, and operational applications would also be conferred with to ensure proper coordination of the U.S. land imaging program and other U.S. remote sensing systems programs with their associated sciences. These include U.S. operational weather, oceans, and atmospheric monitoring systems and programs managed by NOAA, the solar and space physics and exploratory Earth science research programs of NASA, and the operational systems and technology programs managed by the national security community.

The NLIP should report to the Secretary or to an Assistant Secretary of the U.S. Department of the Interior, should be directed by a national leader capable of addressing questions of national and international scope, and should possess the technical and disciplinary skills necessary to demonstrate leadership and excellence in managing a national satellite and data acquisition and management program.

The NLIP should report at this senior level because it is discharging powers and duties of significant scope on behalf of many different interests and activities of the U.S., including matters with direct bearing upon the security, economic welfare, and foreign policy interests of the United States. The Director of NLIP should be empowered to:

- manage civil land imagery needs of the Nation, including the acquisition and operation of U.S.-owned land imaging assets and facilities and distribution of U.S. land imaging data to users in the United States;
- develop and promote U.S. policies to achieve the widest beneficial use of land imaging consistent with the economic, scientific, security, and foreign policy interests of the United States;
- lead, in coordination with other U.S. Government agencies, U.S. efforts to negotiate and ensure U.S. access to imagery data and products from any and all U.S. and international sources;
- assure that land imagery data and information are available throughout the United States for all public and private purposes, including assurance of the means and method of data and information distribution;
- conduct a program of field-based research, development, and training to promote and expand the range of uses of land imagery and related products to meet public needs;
- carry out an advanced technology program necessary to ensure that future U.S. land imagery needs will be met;
- coordinate future land imaging activities and related policy and international coordination plans with the U.S. Group on Earth Observation (USGEO) and the U.S. Integrated Earth Observing System (IEOS); and
- ensure that NLIP costs are accounted and its performance validated using reliable, accurate, user statistics and other performance-based criteria.

Interagency and Public Coordination of the National Program

The NLIP should be advised by a Federal Land Imaging Council consisting of senior representatives from the U.S. Government civilian, intelligence, and military agencies that rely upon land imagery

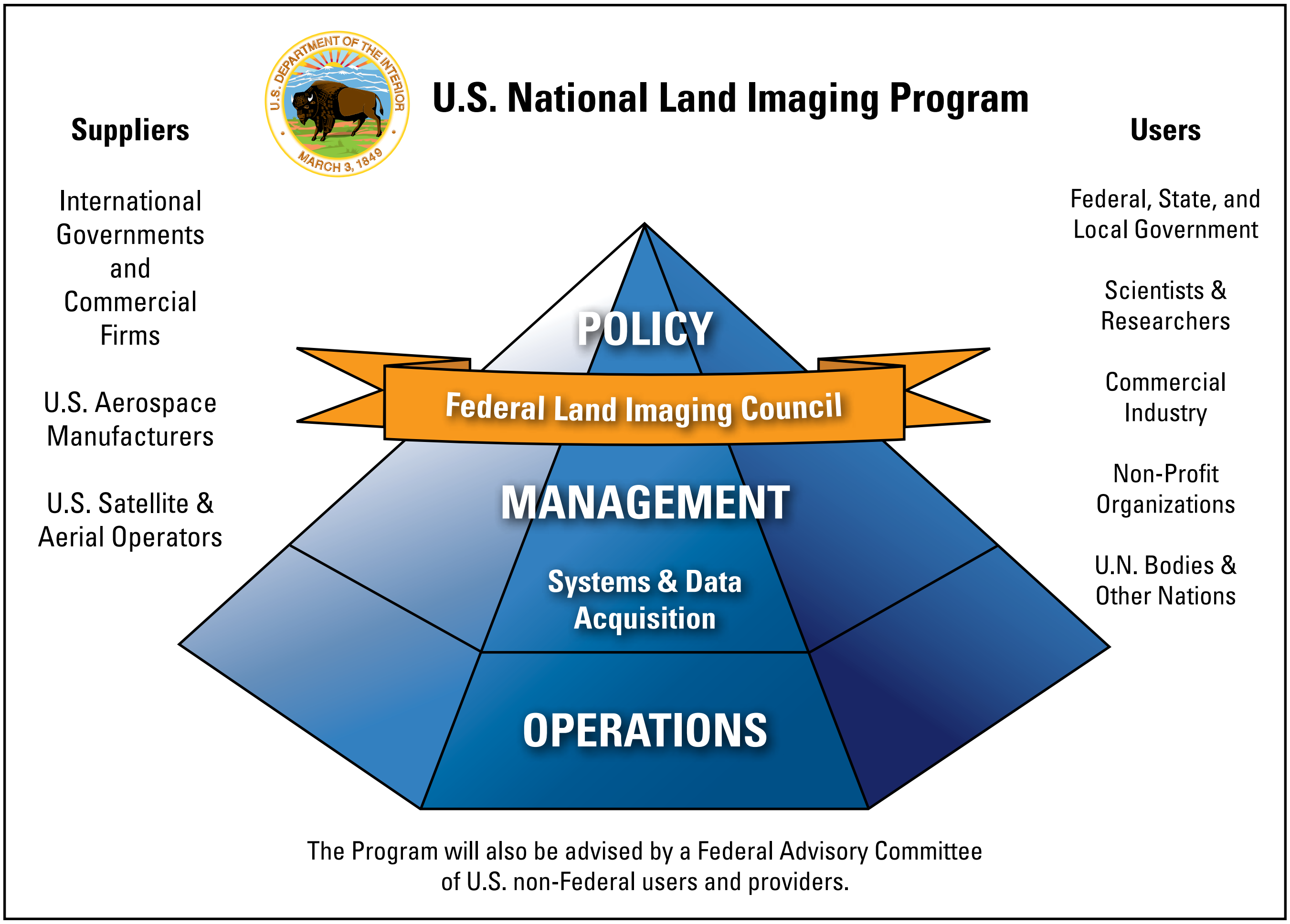

Figure C-1. Structure and organization of the National Land Imaging Program

to conduct U.S. operational programs and activities, including science and research in service to the Nation. The Federal Land Imaging Council may also be called upon to resolve any issues of governance within the U.S. Government regarding land imaging. Figure C-1 describes the structure and components of the National Land Imaging Program, its relationship to external groups, and the relationship between the Council and the program.

The Federal Land Imaging Council would be composed of senior representatives of the various U.S. Cabinet-level departments and independent agencies that either develop or use land imagery. To carry out its oversight and management responsibilities, the Federal Land Imaging Council would meet regularly to reflect upon each agency's mission, address issues related to the use of land imagery and other geospatial products and applications, and regularly assess and assign priorities to the activities of the NLIP.

The Federal Land Imaging Council would be supported by a working group of senior technical and managerial staff that would be chartered with assessing requirements and identifying promising ways of meeting them through the NLIP systems and data acquisition and management program. This working group should also conduct a regular fact-finding process to identify user needs, assess the benefit of NLIP, and forecast future U.S. needs and acquisition requirements. This fact-finding process should be conducted in a rigorous, cross-cutting, public manner with an adequate level of guidance and oversight by the Council.

Under the auspices of the Department of the Interior, NLIP will also establish and support a Federal Advisory Committee composed of a fairly balanced mix of representatives from industry, professional associations, and U.S. State, local and tribal governments who are suppliers or beneficiaries of NLIP. To draw upon the expertise of the Federal Advisory Committee, NLIP will solicit the independent opinions, views, and recommendations of Committee members in the form of discussions, papers, recommendations and/or reports submitted by the Chairman. The Advisory Committee may also establish focused subcommittees to address very specific issues raised by NLIP needing more study, consultation with experts outside of the Advisory Committee's formal membership, and technical or policy attention. After a designated period of time, subcommittees would provide recommendations in the form of reports to the Chairman of the Advisory Committee for the Committee's consideration and use.

U.S. Agency Participation in NLIP

U.S. Department of Agriculture

The U.S. Department of Agriculture (USDA) is the largest operational civil user of moderate-resolution and Landsat-like land imagery. Potential satellite imagery use by USDA is seemingly unlimited, as the primary constraints on satellite imagery use are funding and satellite capacity. For instance, with the implementation of an operational moderate-resolution constellation, USDA would expect a global agricultural area acquisition of 7 days or better and a global seasonal acquisition strategy for forested areas. Moderate-resolution imagery is a crucial resource in monitoring, global agricultural production, forest health, and farm program compliance. The following USDA agencies are current users of moderate-resolution imagery:

- Agricultural Research Service (ARS);
- Animal and Plant Health Inspection Service (APHIS);
- Farm Service Agency (FSA);
- Foreign Agricultural Service (FAS);
- Forest Service (FS);
- National Agricultural Statistics Service (NASS);
- Natural Resources Conservation Service (NRCS); and
- Risk Management Agency (RMA).

The USDA Satellite Imagery Archive (SIA) is the centralized acquisition manager for moderate-resolution and other commercial satellite imagery and is managed by FAS's Global Agriculture Monitoring (GLAM) program (7CFR2.43). FAS and the SIA are also responsible for maintaining active liaison with U.S. space agencies. The SIA is an interagency collaboration with oversight provided by the USDA Remote Sensing Coordinating Committee (RSCC). In a similar manner, USDA plans on consolidating agency membership for the NLIP Federal Land Imaging Council and technical working groups.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA)'s unique mission in Earth science, as mandated by its establishing legislation of the Space Act of 1958, is to "…conduct aeronautical and space activities so as to contribute materially to …the expansion of human knowledge of the Earth and of phenomena in the atmosphere and space." Therefore, NASA's role is unique and highly complementary to the missions and roles of other U.S. agencies (such as NOAA, the National Science Foundation, and the Environmental Protection Agency) by continually advancing Earth system science, creating new remote sensing capabilities, and enhancing the operational capabilities of other agencies and collaborating with them to advance national Earth science goals. NASA will extend this relationship to the National Land Imaging Program (NLIP) and the Department of the Interior to facilitate the accomplishment of the NLIP goals and objectives. Within the NLIP guidelines, NASA will support NLIP activities by:

- participating, along with other relevant agencies, in the development of future operational land surface observation requirements; these new requirements will leverage NASA research to advance operational capabilities and, in turn, provide data for NASA researchers;
- developing science-driven new technologies and capabilities for land imaging;
- transitioning research land imaging technologies and capabilities that have been identified as fulfilling an operational requirement, to land operational systems;
- managing acquisition of operational land observational space systems; and
- sharing NASA's basic research results from the use of space based observations of fundamental

land surface properties and processes and related land science activities.

Department of Commerce, National Oceanic and Atmospheric Administration

NOAA has responsibility, in coordination with NASA, for operational civil environmental space-based remote sensing systems and management of the associated requirements and acquisition process. It is charged along with other agencies to transition mature research and development capabilities to long-term operations. NOAA is also a user of land imaging data primarily for coastal management and change analysis. NOAA is thus prepared to serve on the Federal Land Imaging Council for NLIP and its subsidiary groups and to share in providing management oversight for both the collection of land imaging requirements and the NLIP operational program. NOAA has broad experience of value to NLIP in leading international efforts in the coordination of global Earth observation and in facilitating full and open access to government environmental data. With its responsibility for fostering the development and use to the greatest extent possible of U.S. commercial space capabilities, NOAA will help ensure that NLIP is developed in a manner consistent with maintaining a dynamic, domestic commercial remote sensing sector.

Department of Defense

The Department of Defense (DOD) employs land imaging data to protect U.S. forces and develop intelligence-related information used to address various national security challenges. Although DOD relies primarily on those land imagery collection systems designed to meet its specific mission needs, it is increasing its utilization of data from U.S and foreign commercial and civil systems as they demonstrate unique and/or complementary ways to develop useful information and products. These data enable DOD to have access to potentially more current information over broad regions of the Earth at useful resolution. Moreover, DOD recognizes that finding innovative ways to appropriately utilize civil and commercial data sources holds the promise of being both a cost-effective and highly flexible, adaptable approach for developing data products and information to support U.S. forces on the ground, on the sea, and in the air as well as national policy makers.

Once NLIP is established, DOD will provide an appropriate level of participation to the Federal Land Imaging Council, assist in efforts to chart future requirements and acquire data, and participate in the management oversight of the program. More specifically, DOD will provide its requirements to NLIP for consideration as future civil, operational, land imaging systems and architectures are developed, permitting those future capabilities to address DOD needs as appropriate.

National Geospatial-Intelligence Agency

The National Geospatial-Intelligence Agency (NGA) supports the U.S. warfighter, as well as the imagery requirements of the Department of State and other departments and agencies of the United States outside of the Department of Defense, by utilizing land imagery and geospatial information to describe, assess, and visually depict the Earth's physical features along with various geographically referenced activities. To provide the most accurate, timely, and relevant geospatial-intelligence (GEOINT) information possible to federal users, NGA combines mostly high resolution land information collected from national, civilian, and commercial aeronautical and space-based sources with other geo-referenced information. This information is further exploited using modeling programs, databases, and/or combined with other intelligence disciplines to support national and homeland security requirements.

Once NLIP is established, NGA will actively participate on the Federal Land Imaging Council to ensure that NGA requirements are considered in future operational moderate-resolution land imaging systems. NGA will also assist with the Council's cross-cutting efforts to identify additional geospatial user needs and acquisition requirements for land imaging data provided commercially. Furthermore, NGA will provide opinions, views, and recommendations to the Council consistent with DOD and national policies for the implementation of NLIP objectives.

The Department of State

The Department of State sees multiple diplomatic opportunities for the United States in the international activities of the National Land Imaging Program, including: promoting international science and technology cooperation, facilitating sustainable development among emerging economies, improving transparency and access to data and information about the global environment, and facilitating better stewardship of natural resources around the world. To accomplish its mission, NLIP should be able to use the expertise of both regional and functional Bureaus of the Department, including the Bureau of Oceans, Environment and Science (OES), which in the past has promoted the distribution and access to Landsat data around the world. The Department of State is prepared to participate on the Federal Land Imaging Council in order to add value to any of the international dimensions of NLIP. This can involve improving U.S. Government interagency coordination when negotiating with international providers of civilian satellite data, or helping NLIP in completing international agreements to augment U.S. civil operational land imaging capabilities by leveraging existing bilateral science and technology agreements between the U.S. and its foreign partners.

Funding

It should be noted that the selection of the Single Agency governance model was strongly influenced by the importance of the financial and budgetary stability of this program, a criterion that has never been met previously for the Landsat program. This financial stability would include a single integrated budget request that addresses all facets of systems, data acquisition, operations, data management and distribution, and development and promotion of new experimental techniques, applications, and services relevant to the best use of land imagery by the Nation. This approach would also streamline Executive Branch consideration of a single integrated program budget and allow the U.S. Congress to oversee and discharge its oversight of this essential national program.

The DOI as the Single Agency should manage the NLIP budget formulation and execution processes consistent with U.S. law and regulations. As such, the NLIP should be managed in such a way as to preclude competition for funds with other internal functions of the DOI, including other operational, management, or science programs. This will ensure that funds appropriated for U.S. land imaging are expended solely for the purpose of acquiring, operating, managing, and distributing national land imagery systems and data on behalf of the U.S. Government and the Nation.

Timeline

After the establishment of NLIP, the U.S. Department of the Interior shall accomplish the following initial steps:

- establish a policy and program management office or offices to manage NLIP;
- develop a charter for a Federal Land Imaging Council and a Federal Advisory Committee focused on the future needs and capabilities of U.S. civil moderate-resolution land imaging;
- in coordination with the Federal Land Imaging Council and the Federal Advisory Committee, define a core operational capability for the U.S. moderate-resolution land imaging system;
- develop a strategic plan for U.S. civil operational moderate-resolution land imaging, including a technology plan to meet future needs beginning with the first flight of a Landsat-type national capability;
- formalize a governance model that shall be used by U.S. Federal agencies to coordinate U.S. civil operational land imaging affairs and identify the necessary suite of interagency agreements and memoranda to accompany that model;
- set forth the interagency agreements and protocols that will be used to acquire future civil moderate-resolution land imaging data from international sources;
- initiate a comprehensive index of current U.S. operational moderate-resolution land imaging technical requirements and capabilities, based on a national inventory of U.S. needs and applications of civil operational land imaging data; and
- identify the funding and other resources needed to carry out the duties of the NLIP over the next 10 years.

Figure C-2 on page 49 provides a timeframe for these efforts.

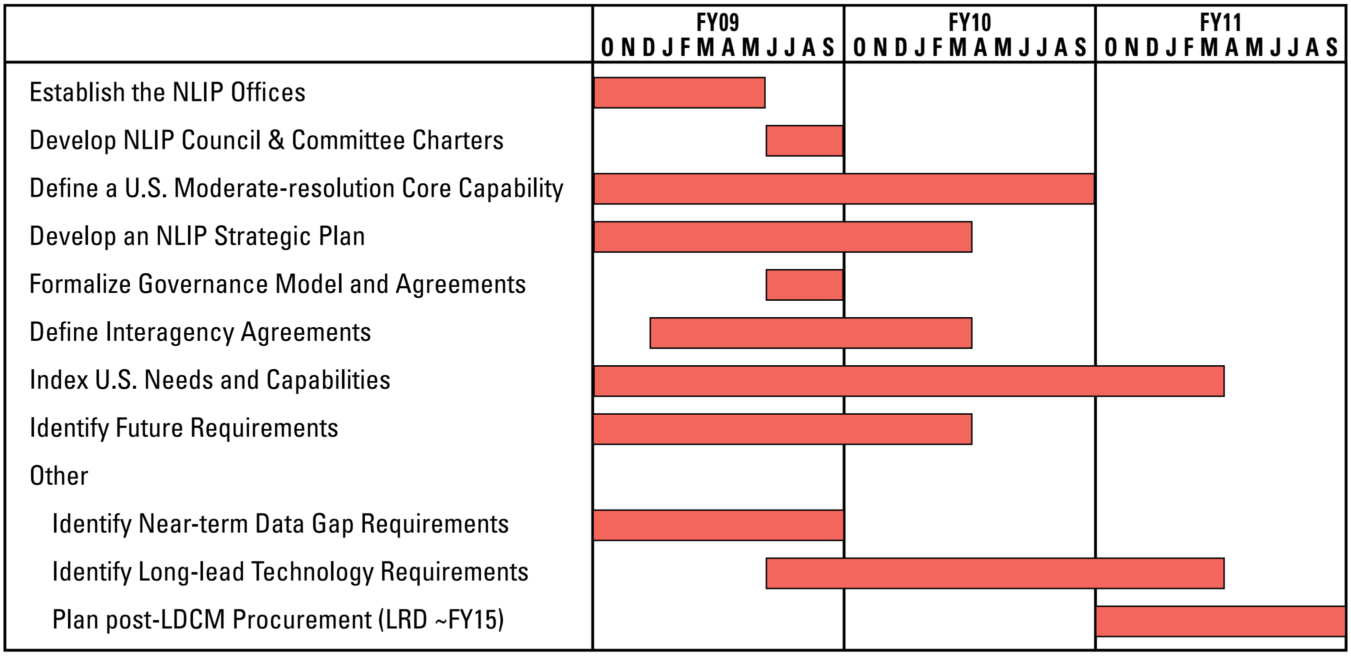

Figure C-2. Initial timeline to establish the National Land Imaging Program (NLIP)

Exhibit 1

"Landsat Data Continuity Strategy Adjustment," Office of Science and Technology Policy (OSTP) Memorandum of December 23, 2005

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

December 23, 2005

MEMORANDUM FOR THE SECRETARY OF STATE
THE SECRETARY OF DEFENSE
THE SECRETARY OF THE INTERIOR
THE SECRETARY OF AGRICULTURE
THE SECRETARY OF COMMERCE
THE SECRETARY OF HEALTH AND HUMAN SERVICES
THE SECRETARY OF TRANSPORTATION
THE SECRETARY OF HOMELAND SECURITY
ADMINISTRATOR, ENVIRONMENTAL PROTECTION AGENCY
ASSISTANT TO THE PRESIDENT FOR NATIONAL SECURITY AFFAIRS
DIRECTOR OF NATIONAL INTELLIGENCE
ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
DIRECTOR, NATIONAL SCIENCE FOUNDATION

FROM: JOHN H. MARBURGER, III
DIRECTOR

SUBJECT: Landsat Data Continuity Strategy Adjustment

This memorandum is to inform you of the outcome of recent discussions among affected agencies and Executive Office of the President (EOP) offices regarding the Landsat program. This memorandum updates and revises the guidance provided in my memorandum of August 13, 2004. That memorandum directed agencies to incorporate Landsat-type sensors on the National Polar-orbiting Operational Environmental Satellite System (NPOESS), and was based on preliminary analysis performed by an interagency study group. Please refer to that memorandum for additional background on the Landsat program leading up to this round of decision-making.

Detailed analysis leads to strategy adjustment

Consistent with the actions outlined in my August 13, 2004 memorandum, the National Aeronautics and Space Administration (NASA), working with the National Oceanic and Atmospheric Administration (NOAA) and other agencies, undertook a detailed analysis of the proposal to incorporate Landsat-type sensors on two selected NPOESS platforms. The results of that technical analysis indicated that the complexities of incorporating Landsat-type sensors on the NPOESS platforms significantly exceeded earlier assessments and made that option less suitable to the goals of both programs. After careful consideration in interagency discussions, all parties agreed that adjustments to the current near-term strategy and development of a new long-term strategy are required in order to ensure the continuity of Landsat-type data.

Ensuring near-term data continuity

The objective of ensuring continuous availability of scientifically sound Landsat-type data can be realized in the near term by revising the Landsat data continuity mission strategy and establishing a plan for data continuity over the longer term. In particular, the Departments of Commerce, Defense, the Interior and NASA will take the following near-term actions:

- Proceed with the NPOESS program without incorporating a Landsat-type instrument;
- NASA will acquire a single Landsat data continuity mission in the form of a free-flyer spacecraft to collect the required land surface data and deliver its data to the Department of the Interior (DOI) / United States Geological Survey (USGS);
- DOI, through the USGS, will be responsible for the operations of the Landsat data continuity mission and for the collection, archiving, processing, and distribution of the land surface data to U.S. Government and other users; and
- The detailed roles and responsibilities of DOI and NASA for this near-term Landsat data continuity mission will be ratified by the two agencies and will be commensurate with the final acquisition approach and selection. The agencies will seek to implement an approach for this mission in a manner that does not preclude a long-term solution for continuity of Landsat-type data.

Ensuring long-term continuity

It remains the goal of the U.S. Government to transition the Landsat program from a series of independently planned missions to a sustained operational program funded and managed by a U.S. Government operational agency or agencies, international consortium, and/or commercial partnership. Concurrent with the actions cited above, the National Science and Technology Council, in coordination with NASA, DOI/USGS, and other agencies and EOP offices as appropriate, will lead an effort to develop a long-term plan to achieve technical, financial, and managerial stability for operational land imaging in accord with the goals and objectives of the U.S. Integrated Earth Observation System.

Exhibit 2
Future of Land Imaging Interagency Working Group (FLI IWG) Charge, Process, and Members

The origin and purpose of this study:

Landsat spacecraft have historically been justified, designed, launched, and operated as experimental, scientific satellites. Despite the broad use of Landsat data by a large number of civil, military, intelligence, commercial and citizen users, the Landsat series of satellites has never been considered a permanent operational program by the U.S. Since 1979, U.S. policy-makers have, on several occasions, driven attempts to commercialize or make semi-private the operation of the Landsat series of satellites, but all of these attempts have failed.

In 1992, the Congress adopted P.L 102-555, The Land Remote Sensing Policy Act, to set Landsat on a new course. This legislation looked to ensuring the continuity of Landsat imagery for U.S. scientific and operational purposes, while establishing provisions for future commercialization of Landsat. Despite these provisions, an attempt to privatize Landsat in 2003 failed to achieve the level of capitalization and commercial market interest necessary to ensure that future U.S. Landsat data continuity requirements would be met.

The current Landsat data continuity strategy, issued on December 23, 2005 by the Office of Science and Technology Policy (OSTP)/Executive Office of the President (EOP), directs the National Aeronautics and Space Administration (NASA), in coordination with the U.S. Department of Interior, United States Geologic Survey (DOI/USGS), to implement a single free flyer Landsat Data Continuity Mission (LDCM) to fulfill near-term Landsat data continuity requirements. The implementation of the Landsat Data Continuity Mission has already begun, as directed, and is not addressed in this report.

The OSTP also directed that *". . . the National Science and Technology Council, in coordination with NASA, DOI/USGS, and other agencies and EOP offices as appropriate, will lead an effort to develop a long-term plan to achieve technical, financial, and managerial stability for operational land imaging in accord with the goals and objectives of the U.S. Integrated Earth Observation System."* As a result, the Future of Land Imaging Interagency Working Group (FLI IWG) was established to conduct a study of future options in land imaging, to provide a strategy for developing and funding those options, and to recommend a governance and management structure to ensure that future U.S. land imaging needs will continue to be met. This report presents that plan.

The structure and process of the study:

As directed by the OSTP memo, the FLI IWG was convened under the auspices of the National Science and Technology Council (NSTC). Under the NSTC Committee on Environment and Natural Resources, the U.S. Group on Earth Observations is leading and coordinating the U.S. effort to facilitate the formation of an Integrated Earth Observation System (IEOS) as part of the Global Earth Observation System of Systems (GEOSS). The work of the FLI IWG is part of that integrated strategy.

The FLI-IWG conducted a comprehensive and objective assessment of current domestic and global land imaging activities, analysis of the National need for such imaging, including the merit and value of the benefits to our Nation and its citizens, identification of any gaps or overlap in ongoing activities, and formulation of recommendations for a path forward.

The FLI IWG established a communications strategy that included providing briefings for the traditional and anticipated land imaging user community and stakeholders to share the purpose and goals of the group's effort.

The communications strategy also included listening sessions at professional meetings, a public workshop, invited guest presentations at the FLI IWG meetings by experts, and a web page (www.landimaging.gov) that provides an opportunity for community input. The FLI IWG partnered with the American Society of Photogrammetry and Remote Sensing (ASPRS) to conduct an extensive survey of the user community to determine current and anticipated needs for moderate-resolution multispectral land imaging. ASPRS survey results, summarized in Exhibit 9, provided the FLI IWG with valuable information and insights.

Although military and intelligence users are most commonly perceived as using high-resolution imagery for meeting their mission requirements, those communities also obtain significant benefit from moderate-resolution land imaging as well. The FLI IWG is cognizant of this situation, has communicated with those communities about their needs, and will provide a classified annex to the final report which describes and explains the nature of moderate-resolution land imaging used in the defense and intelligence communities. The FLI IWG also communicated with members of the U.S. commercial remote sensing industry -- which provides important products and services to the civil, defense, and intelligence communities -- about their future plans.

Members of the Future of Land Imaging Interagency Working Group

- Jeffrey S. Amthor, Office of Science, Department of Energy
- Craig Baker, U.S. Army, Department of Defense
- Glenn R. Bethel, Department of Agriculture
- Barron R. Bradford, U.S. Geological Survey, Department of the Interior
- Raymond A. Byrnes, U.S. Geological Survey, Department of the Interior
- John W. Cullen, U.S. Geological Survey, Department of the Interior
- Bradley D. Doorn, Foreign Agricultural Service, Department of Agriculture
- Eve Douglas, National Oceanic and Atmospheric Administration, Department of Commerce
- Fernando R. Echavarria, Bureau of Oceans, Environment, and Science, Department of State
- Jay W. Feuquay (Deceased), U.S. Geological Survey, Department of the Interior
- Edward C. Grigsby, Earth Science Division, National Aeronautics and Space Administration
- Michael Hales, National Geospatial-Intelligence Agency, Department of Defense
- Theodore F. Hammer, Earth Science Division, National Aeronautics and Space Administration
- James D. Hipple, Risk Management Agency, Department of Agriculture
- Riley D. Jay, National Geospatial-Intelligence Agency, Department of Defense
- Douglas P. McGovern, National Geospatial-Intelligence Agency, Department of Defense
- Rick Mueller, National Agricultural Statistics Service, Department of Agriculture
- Bruce K. Quirk, U.S. Geological Survey, Department of the Interior
- Colonel Patrick H. Rayermann, U.S. Army, Department of Defense
- D. Brent Smith, National Oceanic and Atmospheric Administration, Department of Commerce
- Kuppusamy Thirumalai, Department of Transportation
- Gene Whitney, Office of Science and Technology Policy, Executive Office of the President
- Charles Wooldridge, National Oceanic and Atmospheric Administration, Department of Commerce

Exhibit 3
"Civil Operational Remote Sensing," Presidential Directive, National Security Council: NSC-54, 1979

November 16, 1979

Presidential Directive/NSC-54

TO: The Secretary of State
The Secretary of Defense
The Secretary of Interior
The Secretary of Agriculture
The Secretary of Commerce
The Secretary of Transportation
The Secretary of Energy
The Director, Office of Management and Budget
The Assistant to the President for Domestic Affairs and Policy
The Administrator, Agency for International Development
The Director, Arms Control and Disarmament Agency
The Chairman, Joint Chiefs of Staff
The Director of Central Intelligence
The Administrator, National Aeronautics and Space Administration
The Administrator, Environmental Protection Agency
The Director, Office of Science and Technology Policy
The Director, National Science Foundation

SUBJECT: Civil Operational Remote Sensing

The President has approved the civil space policy discussed below. The policy amplifies that established in PD/NSC-37—National Space Policy and PD/NSC-42—Civil and Further National Space Policy.

2. LAND PROGRAMS. The National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce is assigned the management responsibility for civil operational land remote sensing activities in addition to its ongoing atmospheric and oceanic responsibilities. Initially, the operational land remote sensing system from space will be based on LANDSAT technology. Commerce's initial responsibility—in coordination with other appropriate agencies—will be to develop a time-phased transition plan covering: (1) a Program Board (discussed below); (2) organization for management and regulation; (3) system financing including pricing policies for the users['] sharing of costs; (4) technical programs; (5) establishment of private and international participation; (6) identification of facilities (including the EROS data center), hardware, and personnel that should be transferred; and (7) identification of actions such as executive orders and legislation required. Commerce will submit to OMB a preliminary implementation plan by December 15, 1979, covering any required FY 1981 budget adjustments and a final transition plan by June 1, 1980.

a. Federal Management Mechanism. Commerce will establish and chair a Program Board for continuing federal coordination and regulation with representatives from the involved federal organization (e.g., Defense, Interior, Agriculture, Transportation, Energy, State, NASA, CIA, AID, EPA, and Executive Office of the President). Organizations such as the National Governors' Association and National Conference of State Legislatures will be asked to participate as necessary. The Board will forward recommendations on unresolved policy issues to the Policy Review Committee (Space) for consideration and action.

b. Private Sector Involvement. Our goal is the eventual operation by the private sector of our civil land remote sensing activities. Commerce will budget for further work in FY 1981 to seek ways to enhance private sector opportunities (e.g., joint venture with industry, a quasi-government corporation, leasing etc.). Commerce will be the contact for private industry on this matter and with the Program Board will analyze any proposals received prior to submitting policy issues to the Policy Review Committee (Space) for consideration and action.

Exhibit 3

c. International Participation. The United States will generally support non-discriminatory direct readout to foreign ground stations to continue our present policy and to provide data to foreign users under specified conditions. Pricing policies must be developed that are consistent for foreign and domestic users. We will promote development of complementary nationally operated satellite systems so as to limit US program costs, but protect against unwarranted technology transfer.

3. WEATHER PROGRAMS. Defense and Commerce will maintain and coordinate dual polar orbiting meteorological programs. We will continue procurement of current satellite systems with Defense and Commerce each operating separate satellites to meet the differing needs of the military and civil sectors. When any new polar orbiting satellites are justified they will be jointly developed and procured by Defense, Commerce and NASA to maximize technology sharing and to minimize cost. An appropriate coordination mechanism will be established to assure effective cooperation and to prevent duplication.

4. OCEAN PROGRAMS. If a decision is made to develop oceanographic satellites, joint Defense/Commerce/NASA development, acquisition and management will be pursued. A Committee will be established, with the above representation expanded to include State, CIA, and NSF. The Committee will forward recommendations on policy issues to the Policy Review Committee (Space) for consideration and action.

Zbigniew Brzezinski

Exhibit 4

"The Landsat Program: Its Origins, Evolution, and Impacts," Reprint from *Photogrammetric Engineering & Remote Sensing*, July 1997

The Landsat Program: Its Origins, Evolution, and Impacts

Donald T. Lauer, Stanley A. Morain, and Vincent V. Salomonson

Abstract

Landsat 1 began an era of space-based resource data collection that changed the way science, industry, governments, and the general public view the Earth. For the last 25 years, the Landsat program — despite being hampered by institutional problems and budget uncertainties — has successfully provided a continuous supply of synoptic, repetitive, multispectral data of the Earth's land areas. These data have profoundly affected programs for mapping resources, monitoring environmental changes, and assessing global habitability. The societal applications this program generated are so compelling that international systems have proliferated to carry on the tasks initiated with Landsat data.

Introduction

Civilian land remote sensing satellite systems are currently being operated by the United States, France, India, Japan, Canada, Russia, and the European Space Agency. On command, all of them make measurements of the land surface, transmitting data to a global network of strategically located ground receiving stations. Data from these Earth-observing satellites are used to map, monitor, and manage Earth's natural and cultural resources.

The United States pioneered land remote sensing from space and has been the unquestioned leader of this unique technology. Americans take pride in having developed the Landsat program and other, more recent, civilian programs. The evolution of Landsat, however, has been neither linear nor predictable. This paper provides an overview of its conception, genesis, and growth; its accomplishments and current status; and its uncertain future.

The Road to Landsat

Perhaps the first person who believed that not only machines but humans, too, could venture into space was Jules Verne, a French provincial lawyer with no scientific or technical training (Mark, 1984). Verne, in 1865, made the extraordinary prediction that a rocket would be launched from Florida by means of chemical propulsion and that the crew would include three people (and a dog). First they would only circle the Moon and return to Earth, as did Apollo 8. This would be followed by a trip to the Moon's surface, returning to Earth with a "splash down" in the Pacific Ocean and recovery by a warship. Perhaps Verne's most remarkable prediction was that this first journey would be made by Americans. What he did *not* predict was that astronauts would be awed by "the blue marble," or that their photographs would so sensitize the world, that subsequent human scientific interest would shift toward space as a means for studying the Earth. The United States was not only the first to land a spacecraft on the Moon, but, beyond Verne's vision, it also developed the first remote sensing satellites whose profound importance in today's sense of a global village cannot be overstated.

In 1946, the United States Army Air Corps requested that RAND Corporation consider how objects might be inserted into orbit (Mark, 1988). The study resulted in a report, *Preliminary Design of an Experimental World-Circling Spaceship* (Burrows, 1986). The proposed midget moon, or "satellite," would provide "...an observation aircraft *[sic]* which cannot be brought down by an enemy who has not mastered similar techniques." After many aborted lift-offs and system failures, the military successfully launched its first Earth-observing satellite in August 1960. It was called Discoverer and was expected to be an unclassified system to support biomedical research and Earth observations (Tsipis, 1987; Whelan, 1985). A few months after launch, however, a Presidential Directive classified the Discoverer program and plunged it into deep secrecy. Only recently have images collected by its successor, the Corona program, been declassified for public use (McDonald, 1995).

Parallel to the early military/intelligence programs in space, the scientific and industrial communities in America were awakening to the potential of space for providing a new world perspective. In 1951, six years before Sputnik 1, Arthur Clarke, a science fiction writer and prophet of technology, proposed that a satellite could be inserted into orbit over the North and South Poles while the Earth revolved beneath it, and that this satellite would permit humans to view the planet in its entirety (Fink, 1980). In April 1960, the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) launched the Television and Infrared Observational Satellite (TIROS-1) into such an orbit, inaugurating the first experimental weather satellite (U.S. Dept. of Commerce and Nat'l. Aero. and Space Admin., 1987). This system generated the first television-like pictures of the entire globe in a systematic and repetitive manner. This ongoing series of TIROS satellites became operational in 1966 as the TIROS Operational Satellites (TOS), and in 1970 were renamed by the National Oceanic and Atmospheric Administration (NOAA) the Polar Orbiting Environmental Satellites (POES) (Morain and Budge, 1995).

D.T. Lauer is with the U.S. Geological Survey, EROS Data Center, Sioux Falls, SD 57198 (lauer@edcmail.cr.usgs.gov).

S.A. Morain is with the Department of Geography and Earth Data Analysis Center, University of New Mexico, Albuquerque, NM 87131 (smorain@spock.unm.edu).

V.V. Salomonson is with the National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, MD 20771 (vsalomon@pop900.gsfc.nasa.gov).

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Growing the Science Community

The Environmental Research Institute of Michigan (ERIM), formerly the Institute of Science and Technology at the University of Michigan, is credited with organizing in February 1962 the first technical conference on remote sensing in the United States, perhaps the world. Its *First Symposium on Remote Sensing of Environment*, sponsored by the Navy's Office of Naval Research (ONR) had 15 presenters and 71 participants (Environ. Res. Instit. of Michigan, 1962). One of the presenters, who represented the U.S. Department of the Interior (DOI), was the U.S. Geological Survey's (USGS) Dr. William Fischer, an early advocate of an Earth-observing system. The field was so new that Dana Parker, an organizer of the Symposium, focused his inaugural address on fundamentals of the electromagnetic spectrum. In October 1962, the second symposium drew 162 participants to hear 35 technical papers (Environ. Res. Instit. of Michigan, 1963). It was sponsored by the Geography Branch of ONR, the Air Force Cambridge Research Laboratory, and the Army Research Office.

At the third symposium in October 1964, 280 participants heard 54 technical papers (Environ. Res. Instit. of Michigan, 1965). By this time, all of the principal government, academic, and private-sector motivators for an orbiting resource satellite system were represented. Among the papers in the *Proceedings* was one by Dr. Robert Alexander of *ONR*. He announced what evolved into Landsat 1. His abstract read:

> *The National Aeronautics and Space Administration is sponsoring a study of the geographic potential of observations and experiments which might be carried out from the remote vantage of earth-orbiting spacecraft. The investigation will involve both the value of the science of geography and the expected practical applications of an earth-viewing-orbiting laboratory and other possible geographic satellite systems. Early emphasis will be on problems of systematizing and managing the flow of geographic information which would result from such a program* (p. 453).

The eighth symposium (Environ. Res. Instit. of Michigan, 1972), held eight years after Alexander's announcement and only a few weeks after the first Landsat 1 images were released, included 14 presentations describing the utility and quality of these data. By that time, the broader field of remote sensing attracted more than 700 participants who selected from a program of 116 papers on topics including theoretical and applied engineering, natural and cultural resources monitoring, state and local government applications, and even subjects addressing environmental and public health issues.

NASA became an official sponsor of the ERIM symposia in 1971. In 1973, NASA's Administrator inaugurated its decade-long program of University Research Grants to stimulate cooperative research at the local level. In some cases, it assisted construction of laboratory facilities and supplied the equipment to train the 1970's generation of Ph.D. remote sensing specialists. By the mid- to late-1970s, many of these young professionals were employed on collaborative Federal Government research projects for "proof-of-concept" applications embracing the whole range of natural and cultural resources. The Large Area Crop Inventory Experiment (LACIE) and the subsequent AgriSTARS are examples of these. The Application System Verification Tests (ASVTs) are others.

While these were not the only applications development programs under way, they were symptomatic of a massive, spontaneous adaptation to fundamentally new ways of studying the Earth. Within little more than a decade of ERIM's first symposium, the core remote sensing community increased its numbers by several orders of magnitude. Their efforts brought about major changes in organizational structures, became the basis for a new international research agenda, and germinated the seeds of thought for global habitability studies.

Stimuli for an Earth-Orbiting Resource Satellite

The forces that emanated from the science community, private sector, and government and stimulated today's Landsat program were numerous and complex. Five of the most compelling were (1) the need for better information about Earth features, (2) national security, (3) commercial opportunities, (4) international cooperation, and (5) international law.

Need for Better Information. *Society requires better information about the geographic distribution of Earth resources, and satellites will help obtain this information.* The Earth now supports more than five billion people, and human populations are growing at 1.5 percent per year, or three people per second. By the year 2000, the number will exceed six billion. Nobody knows how many people the Earth can sustain; some guess eight billion, but others say nearly double that (McRae, 1990; Ashford and Noble, 1996). No matter how many people can be squeezed onto the planet, however, there are limits to the renewable and nonrenewable resources needed to support them. Efficient management of renewable resources and judicious use of nonrenewable ones, as well as improved conservation and protection of fragile and endangered environments, depend upon timely information about, and accurate analysis of, those resources. In the late 1960s, there was a convergence of thought that the best means for acquiring needed data rested on Earth-orbiting satellites that could provide continuous and nearly synoptic coverage of terrestrial resources. Such coverage would be especially useful for understanding and measuring Earth-system processes at regional, continental, or global scales. Human numbers and human impacts on resources thus became an early and globally compelling argument to study the Earth.

National Security. *The United States Government maintains national security, which includes using data from civilian satellites to protect and defend the Nation against aggressors.* It is no secret that defense/intelligence satellites are assets for maintaining national security. It is not as widely known, however, that the defense/intelligence community has always employed data from civilian satellite systems to carry out its security mission (National Space Council, 1989). While there were, and still are, many security limitations imposed on the first generation of civilian Earth-observing systems, there was nevertheless a defensible argument that such a system should be developed. Timely information about the global distribution of critical natural resources, and the factors that affect global environmental conditions, are integral to national security and would be augmented by civilian systems. Indeed, the decision to build and launch Landsat 7 was partly driven by requirements of the defense/intelligence community (White House, 1992).

Commercial Opportunities. *To benefit from the powers of the free enterprise system, the United States Government encourages private-sector investment in the Nation's space program, including civilian Earth-observing satellites.* Remote sensing technology was developed by aerospace industries under contract to Federal Government agencies to satisfy both government and public needs. Commercializing this know-how is fundamental to American ideals and has been a stimulus for continued industry investment. By the early 1970s, several industries had already proven the commercial value of the space environment. These included communications satellites and booster launch services. The prospects for similar financial gain from Earth resources data seemed evident, but a successful experimental system would be a necessary first step. Commercial space-based remote sensing products and services finally will be tested in 1997 when several privately owned satellites are scheduled for launch. The assumption that Earth resources data would have commercial value beyond those for the public good was thus a powerful argument for developing the Landsat program. Full commercialization of both the space and ground segments might yet prove to be intractable, but there is clearly a viable and profitable role for industry to build launch vehicles, space platforms, sensor systems, and ground processing facilities, and to provide value-added data processing services.

International Cooperation. *The United States Government seeks international cooperation in civilian Earth-observing satellites to better understand, manage, share, and protect Earth resources.*
The United States is committed to using space for peaceful as well as defense purposes. Toward this end, Americans want to share benefits from space technology with other nations, but they also want to protect their commercial interests. Earth observations from space have never been the sole domain of the United States, and several nations now participate in this activity with competing spacecraft and sensor systems. The argument for promoting cooperation among nations is based on the apparent redundancy between different national programs, the obvious savings to be gained in joining programs through the sharing of costs, and the opportunity for the United States to promote its foreign policy objectives (White House, 1996).

International Law. *Societies are governed by laws, rules, and regulations to maintain organization and order — not only on Earth, but also in space.*
Societies establish laws by which they govern against chaos and anarchy. Space law is relatively new to jurisprudence, but it is a central force because it sets the rules by which all nations, not just the spacefaring ones, have a voice in how to participate in space technology. Legal aspects of civilian space-based remote sensing are complicated and sometimes controversial, especially regarding the issues of national sovereignty, rights of privacy, and, most recently, commercial gain. The United States has always argued strongly for an open skies and nondiscriminatory data distribution policy for civilian space data, believing that the greatest good for the greatest number can come from free and open exchanges of data and information (Stowe, 1976; White House, 1988). When the United States undertook the Landsat program, it made an extraordinary effort to ensure that every nation had access to these data, even to the extent that foreign ground receiving stations were installed.

Evolution of the Program

The Landsat Concept

The concept of a dedicated, unmanned land-observing satellite emerged in the mid-1960s from this complex milieu of synergy and conflicting interests. It arose primarily in the ONR and NASA, and in the USGS under its late director, Dr. William T. Pecora (Waldrop, 1982). In fact, scientists within the USGS, working in cooperation with Dr. Archibald Park and others in the United States Department of Agriculture (USDA), originally proposed to the Bureau of the Budget (now Office of Management and Budget) to build, launch, and operate an Earth Resources Observation Satellite (EROS). The Under Secretary of the Interior announced the objectives of EROS in a memorandum dated 12 July 1967, and addressed to the DOI's Assistant Secretaries and Bureau heads (Luce, 1967). These objectives were to (1) construct and fly an Earth-observing system by the end of 1969 and to follow with improved systems as required by operational needs of resources programs; (2) provide unclassified remotely sensed data to facilitate assessment of land and water resources of the United States and other nations; and (3) design specific systems on the basis of data user requirements, distribute such data to users, and make operational use of the data in resource studies and planning. The overall goal of the proposed EROS program was to acquire remotely sensed data from satellites in the simplest possible way, deliver these data to the user in an uncomplicated form, and ensure their easy use (Pecora, 1972).

Because development of space technology was NASA's responsibility, the DOI proposal was rejected by NASA Administrator James Webb, who met with President Johnson to discuss DOI's announcement. Webb succeeded in exercising NASA's control of what was to become an "experimental" program (Covert, 1989). In cooperation with DOI, USDA, and other agencies, NASA designed an Earth-observing satellite, obtained funding for the project, and successfully launched in July 1972 the first Earth Resources Technology Satellite (ERTS-1), which was later called Landsat 1.

Although unsuccessful with its own "operational" satellite system, the Department of the Interior continued with an Earth Resources Observation Satellite[1] (EROS) program under the direction of USGS. The EROS mission was to archive and distribute remotely sensed data, and to support remote sensing research and applications development within the DOI. To carry out the EROS responsibilities, the USGS built the EROS Data Center in Sioux Falls, South Dakota, in 1972.

Conflicts in agency roles began to appear even as the first Landsat was being prepared for launch. NASA's charter was to engage in space research and technology development. It did not include Earth resource data handling, processing, archiving, or distribution to a large and diverse scientific community, or to an even larger group of public and private users. Consequently, NASA reached agreement with USGS and several resource management agencies to transfer responsibility for the program's ground segment to the USGS, while NASA retained responsibility for the space segment.

After the launch of Landsat 1, NASA's Goddard Space Flight Center (GSFC) hosted a series of symposia in quick succession starting in March 1973 (Nat'l Aero. and Space Admin., 1973). These were designed especially for the Landsat-sponsored investigators to report "user identified significant results." The application categories were agriculture/forestry, environment, geology, land use/land cover, water, and marine. Each of the *Proceedings* approached 2,000 pages of text and graphics, mostly detailing early application concepts and models. The Landsat program had such a powerful impact in so many application arenas that management of the program became the subject of a prolonged debate between participating government agencies (U.S. Dept. of Commerce, 1980).

In the decades following Landsat 1, the program experienced severe political uncertainty and was casually labeled a "technology in search of an application." Thomas S. Kuhn's prescription for scientific revolutions forewarned these developmental stages by predicting a period of scientific uncertainty, if not outright denial, by whole sectors of the science and technology community (Kuhn, 1962). Once the critical mass of support was reached, the individual actions of sensor developers, data suppliers, data analysts, and end users

[1]Later the "S" in EROS was changed from "Satellite" to "Systems."

Exhibit 4

TABLE 1. BACKGROUND INFORMATION AND STATUS OF LANDSAT SATELLITES.

Satellite	Launched	Decommissioned	Sensors
Landsat 1	23 Jul 1972	06 Jan 1978	MSS and RBV
Landsat 2	22 Jan 1975	25 Feb 1982	MSS and RBV
Landsat 3	05 Mar 1978	31 Mar 1983	MSS and RBV
Landsat 4	16 Jul 1982	*	TM and MSS
Landsat 5	01 Mar 1984	**	TM and MSS
Landsat 6	05 Oct 1993	***	ETM
Landsat 7	May 1998****		ETM+

* in standby mode
** operational
*** never achieved orbit
**** anticipated launch

ensured continuation of the technology, even if it seemed chaotic, and even if the directions of development were obscure. After a quarter century of successful data gathering, the fate of the Landsat program beyond Landsat 7 remains uncertain, but the technology derived from it continues to permeate user communities and becomes more complex as the applications it spawned mature.

The Landsat System

ERTS-1 was launched from Vandenberg Air Force Base in California on 23 July 1972. A Nimbus-type platform was modified to carry the sensor package and data-relay equipment. ERTS-2 was launched 22 January 1975. It was renamed Landsat 2 by NASA, which also renamed ERTS-1 to Landsat 1. Three additional Landsats were launched in 1978, 1982, and 1984 (Landsats 3, 4, and 5, respectively). As documented by the USGS (1979) and by the USGS and NOAA (1984), each successive satellite system had improved sensor and communications capabilities (Table 1).

Landsats 1, 2, and 3

The first three Landsats operated in near-polar orbits at an altitude of 920 km. They circled the Earth every 103 minutes, completing 14 orbits a day and produced a continuous swath of imagery 185 km wide. Eighteen days and 251 overlapping orbits were required to provide nearly complete coverage of the Earth's surface. The amount of swath sidelap varied from 14 percent at the Equator to nearly 85 percent at 81° north or south latitude. These satellites carried two sensors: a return beam vidicon (RBV) and a multispectral scanner (MSS). The RBV sensor was a television camera designed for cartographic applications, while the MSS was designed for spectral analysis of terrestrial features. The MSS sensor scanned the Earth's surface from west to east as the satellite moved in its descending (north-to-south) orbit over the sunlit side of the Earth. Six detectors for each spectral band provided six scan lines on each active scan. The combination of scanning geometry, satellite orbit, and Earth rotation made possible the global coverage originally suggested by Arthur Clarke for viewing Earth's entire land surface. Spatial resolution of the MSS was approximately 80 m with spectral coverage in four bands from visible green to near-infrared (IR) wavelengths (Table 2). Only the MSS sensor on Landsat 3 had a fifth band in the thermal-IR.

TABLE 2. RADIOMETRIC RANGE OF SPECTRAL BANDS AND SPATIAL RESOLUTION FOR THE MSS SENSOR (FROM *LANDSAT DATA USERS HANDBOOK*, USGS, 1979 AND USGS AND NOAA, 1984).

Landsats 1, 3	Landsats 4, 5	Wavelength (µm)	Resolution (metres)
Band 4	Band 1	0.5–0.6	79/82*
Band 5	Band 2	0.6–0.7	79/82
Band 6	Band 3	0.7–0.8	79/82
Band 7	Band 4	0.8–1.1	79/82
Band 8**		10.4–12.6	237

* The nominal altitude was changed from 920 km for Landsats 1 to 3 to 705 km for Landsats 4 and 5 which resulted in a resolution of approximately 79 and 82 metres, respectively.
** Landsat 3 only.

Landsat 1 delivered high-quality data for almost five years beyond its designed life expectancy of one year and was finally shut down on 6 January 1978. Landsats 2 and 3 were decommissioned in February 1982 and March 1983, respectively, both well beyond their design lifetimes.

Landsats 4 and 5

Landsats 4 and 5, still partially operational at this writing, and carry both the MSS[2] and a more advanced sensor called the thematic mapper (TM). At 705 km, their orbit is lower than their predecessors', and provides a 16-day, 233-orbit repeat cycle with image sidelap that varies from 7 percent at the Equator to nearly 84 percent at 81° North or South latitude. The MSS sensors aboard Landsats 4 and 5 are identical to earlier ones. Both sensors detect reflected radiation in the visible and near infrared (VNIR), but the TM sensor provides seven spectral channels of data compared to only four channels collected by the MSS. The wavelength range for the TM sensor spans the blue through the mid-IR spectra (Table 3). Sixteen detectors for the visible and mid-IR wavelength bands in the TM sensor provide 16 scan lines on each active scan. The TM sensor has a spatial resolution of 30 m for the visible, near-IR, and mid-IR wavelengths and 120 m for the thermal-IR band. Like all earlier Landsats, sensors on these satellites image a 185-km swath. Landsat 4 has lost nearly all capability to transmit data and is in standby mode. Landsat 5 has lost its Tracking and Data Relay Satellite System (TDRSS) capability, but continues to provide data via direct downlink to the United States and the international ground stations.

Landsat 6

Landsat 6 was launched 5 October 1993, but failed to achieve orbit. It was similar to Landsats 4 and 5 in terms of spacecraft design and planned orbital configuration. The MSS and TM sensors were replaced by an improved TM sensor called the enhanced thematic mapper (ETM) from which, of course, no data were received.

Assessing the Impact

Landsat 1 not only inaugurated a global research agenda, but also spawned a new category of careers in engineering and the natural sciences. Arguably, Landsat 1 provided academic geographers and other researchers with real-world data to apply and test their theoretical models, thus giving access to a first new set of spatial analytical tools since the electronic calculator. At first, Landsat 1 augmented, and then gradually changed, the 1960's approach to remote sensing as a multispectral tool, to one capable of adding time to the analytical toolkit for studying and monitoring Earth resources.

As expected, Landsat 1 promoted business applications for Earth resources data and stimulated a proliferation of complementary international platforms. Both the *American* and *International Societ[ies] of Photogrammetry* quickly added *Remote Sensing* to their organizational titles, as adoption of the technology produced a flood of new members and research foci. In short, Landsat 1 broadened participation and coalesced a diverse community of devoted practitioners into an international body whose collective efforts gave birth to a new remote sensing science. Like all such phenomena in

[2]Routine collection of MSS data over North America was terminated in late 1992.

TABLE 3. RADIOMETRIC RANGE OF SPECTRAL BANDS AND SPATIAL RESOLUTION FOR THE TM SENSOR (FROM *LANDSAT DATA USERS HANDBOOK*, USGS AND NOAA, 1984).

Landsats 4, 5	Wavelength (μm)	Resolution (metres)
Band 1	0.45–0.52	30
Band 2	0.52–0.60	30
Band 3	0.63–0.69	30
Band 4	0.76–0.90	30
Band 5	1.55–1.75	30
Band 6	10.40–12.50	120
Band 7	2.08–2.35	30

the throes of birth, growth of remote sensing technology was partly ordered and partly chaotic; after 23 July 1972, it evolved into a complex system of technology developers, data suppliers, and data analysts and users. Landsat 1 data became the keystone around which the technology would adjust and grow.

A New Paradigm

A premise of remote sensing is that the Earth's features and landscapes can be discriminated, identified, categorized, and mapped on the basis of their spectral reflectances and emissions. Pre-Landsat literature in the ERIM symposia reveals this focus. Sensor designs spanned the electromagnetic spectrum from ultraviolet wavelengths to passive and active microwave frequencies. The multispectral concept combined sensors across these electromagnetic regions, and partitioned within them, to study the spectral domains of the hydrosphere, lithosphere, biosphere, and atmosphere. NASA, among other government agencies, contracted with industry to develop 12-, 24-, and 48-channel scanners for aircraft research in geology, agriculture, forestry, and land use and land cover. Major emphasis was on building libraries of spectral reflectances under controlled laboratory conditions and through data gathered by aircraft. Interpretation keys and crude machine-processing algorithms were commonly employed to identify features, but with a persistent apprehension that such results were, in each case, riveted to a study area's specific time and space.

The Landsat 1 MSS sensor fit into this framework as a four-channel, wide-bandwidth scanning system designed for first-order observations of surface covers from space altitudes — for essentially all of the Earth's land surface. These basic phenomena included the global land/water interface, vegetated/unvegetated areas, forested/unforested lands, urban/nonurban areas, and agricultural/nonagricultural lands. Each category of these observations is the foundation for increasingly sophisticated interpretations of economic uses of the land, for assessing environmental health, and for addressing what would later be called *Earth System Science* (Nat'l Aero. and Space Admin., 1988).

By virtue of its 18-day orbital repeat cycle, it was also recognized that Landsat 1 would offer scientists their first significant opportunity to observe synoptic changes in surface covers that had been difficult to record using aerial platforms. The temporal dimension of remote sensing had always been appreciated, but seldom usefully employed outside the Department of Defense because high-quality time-series data were essentially nonexistent. With Landsat 1, the time dimension not only was a key design parameter, but also was immediately recognized by the scientific community as an essential ingredient in spectral analyses. By holding solar azimuth relatively constant with an equatorial crossing of approximately 9:30 AM local time, the orbital design offered an opportunity to radiometrically calibrate spectral readings across latitudes and longitudes and throughout the annual greening and yellowing cycles of vegetation. Attention moved sharply away from building spectral libraries to monitoring temporal changes and patterns.

Time was also the enabling parameter for promoting a deeper understanding of physical models in several land analysis applications (Reeves, 1975; Colwell, 1983). In surface hydrology, for example, measurements from data collection platforms (DCP's) were merged experimentally with Landsat 1 data to monitor spatial and temporal changes in water levels of Lake Okeechobee (Florida) to better understand the swamp ecology and Miami's urban water needs. Run-off prediction models were augmented by monitoring the geographic extent and depth of river basin snow levels; and temporal dynamics of major floods like those occurring along the Mississippi River and Cooper's Creek (Australia) in 1973 were examined for purposes of disaster assessment.

Other time-sensitive applications were also advanced. In agriculture, MSS imagery was used to improve an existing production estimation model for wheat in western Kansas, proving that satellite-acquired data could facilitate accurate and timely crop predictions (Morain and Williams, 1975). Forest clearcuts in Oregon and Washington were monitored, and in Washington were actually used to assess lessee compliance with timber harvest licenses. Rangeland studies included spectral responses through time to assess biomass production and general range condition.

These early modeling efforts evolved into satellite applications that address today's social and environmental issues (e.g., food security, deforestation impacts, desertification trends, resource sustainability, and news gathering). None of them, however, led directly to these more profound applications. They all needed iterations that included many false starts. Early applications, therefore, were important as pioneering efforts and for what they taught scientists about future satellite requirements and the need for collateral input for problem solving. All of the Landsat 1 results relied on collateral, ground-based data [today's relational database, or geographic information system (GIS), technology] and suffered from gaps in temporal data that would have made them more robust. Furthermore, the spectral data often were too coarse. If satellite-based Earth observations were to deliver on their early promise, then more spectral channels having narrower bandwidths would have to be acquired from a larger number of platforms providing more frequent observation. If this could be achieved, it was believed with certainty that the data and imagery would have commercial, as well as public, value.

Privatization/Commercialization

NASA, as the Nation's civilian research and development space agency, successfully executed its role by launching Landsat 1. The hand-off of responsibility for data dissemination from NASA to the USGS's EROS Data Center was already completed by the time Landsat 1 was launched. The plan was for the USGS to serve as the supplier of Landsat products, while NASA continued to develop future sensors and platforms. Differing responsibilities and management agendas at NASA, NOAA, DoD, USDA, and USGS, however, plagued the Landsat program from its inception. To resolve these varying agency responsibilities, the Carter Administration undertook an extensive review of both military and civilian space policies, and by 1979 new policies were formulated in which the civilian program was to be made operational, administered by NOAA, and eventually turned over to the private sector (U.S. Dept. of Commerce, 1980; White House, 1979). At about this same time Congress merged land-, ocean-, and weather-sensing systems under the administration of NOAA in the Department of Commerce (DOC).

A crisis ensued (National Research Council, 1985). The

Exhibit 4

major players in this crisis included a burgeoning community of Landsat data users, among them the news media, who wanted inexpensive, publicly accessible data; an increasingly vociferous industrial sector concerned about pending international competition and who believed privatization would preserve America's niche in commercial Earth observations; and a federal establishment disinclined to commercialize all land, ocean, and weather satellite data systems.

In its effort to reduce the size of government, the first Reagan Administration acted quickly to move the Landsat program to the private sector. The result was Public Law 98–365, the *Land Remote-Sensing Commercialization Act of 1984* (U.S. Congress, 1984). NOAA solicited bids to manage the existing Landsats and civilian meteorological satellites and, aided by large government subsidies, to build and operate future systems. Proposals were received from such diverse bidders as aerospace companies, an insurance company in New York, a small geoscience firm in Michigan, and a farmer in North Dakota (U.S. Dept. of Commerce, 1984). In 1985, a contract was signed with EOSAT Company and the transfer of the Landsat system but not the weather satellites was complete (U.S. Dept. of Commerce, 1985).

A history of the national debate leading up to and going beyond privatization is given by Morain and Thome (1990). It is interesting that the most compelling arguments given to Congress for Landsat commercialization focused on data and program continuity — not spectral analyses and fine-resolution, time-sequential data. In spite of the fact that data continuity was never defined, and that program continuity remains a political question, Congress continues to legislate most aspects of America's space remote sensing activities.

Following extensive study by NOAA (U.S. Dept. of Commerce, 1988) and another series of program reviews, the National Space Council released its National Space Policy Directive #5, establishing new goals and implementation guidelines for the Landsat program (White House, 1992). The Directive called for a joint DoD/NASA effort to build, launch, and operate Landsat 7. In October 1992, the Land Remote Sensing Policy Act (P.L. 102–555) was signed into law. This law reversed the 1984 decision to commercialize the Landsat system and recognized the scientific, national security, economic, and social utility of "land remote sensing from space" (Sheffner, 1994). The law mandated DoD and NASA to (1) establish a management plan, (2) develop and implement an advisory process, (3) procure Landsat 7, (4) negotiate with EOSAT for a new data policy regarding existing systems, (5) assume program responsibility from DOC, (6) conduct a technology demonstration program, and (7) assess options for a successor system (U.S. Congress, 1992).

Hardly a year had passed before the Landsat program was evaluated for a third time, principally because of severe budget constraints surrounding the high resolution multispectral stereo imager instrument proposed by DoD for Landsat 7. The National Science and Technology Council (NSTC) recommended that Landsat 7 be developed only with an improved TM instrument and that a new management structure be established so that DoD could withdraw from the program. This resulted in Presidential Decision Directive/NSTC-3, dated 5 May 1994, reconfirming the Administration's support for the program but giving NASA, NOAA, and the USGS joint management responsibility (White House, 1994). These three agencies negotiated with EOSAT for new Landsat 4 and 5 product prices for the U.S. Government and its affiliated users, and are proceeding to develop Landsat 7. Meanwhile, a worn but operable Landsat 5 (into its 14th year!) remains aloft, transmitting consistent and reliable TM images of the Earth to the United States ground station and its foreign counterparts.

Government policies designed to transfer the Landsat program from the public to the private sector were seriously flawed. These policies did not result in market growth, were more costly to the Federal Government than if the system had been federally operated, did not significantly reduce operating costs, and significantly inhibited applications of the data (Lauer, 1990). Nevertheless, the program continued to provide a flow of high-quality, well-calibrated, synoptic imagery of the Earth.

Whether or not Landsat privatization was premature given existing and anticipated markets, it can be argued that an expanding global community of government, academic, and private sector users, particularly among developing nations in Africa, Latin America, and Asia, stimulated proliferation of international Landsat look-alike satellites. After 1986, these systems augmented Landsat data around the world, further verifying proof-of-concept applications, and boosting overall space-based capabilities to a new level.

The Legacy

Landsat 7

Landsat 7 is scheduled for launch in mid-1998. Its payload will be an enhanced thematic mapper (plus) instrument, designated the ETM+. It has the same basic design as the TM sensors on Landsats 4 and 5 but includes some conservative advancements (Obenschain *et al.*, 1996). It will provide 60 m (as opposed to 120 m) spatial resolution for the thermal-IR band and a full-aperture calibration panel leading to improved absolute radiometric calibration (5 percent or better). The geodetic accuracy of systematically corrected ETM+ data should be comparable to that characterizing Landsat 4 and 5 TM data with a specific uncertainty of 250 m (one sigma), or better. Other features have been added to the Landsat 7 program to facilitate use of the data. For example, Landsat 7 will directly downlink ETM+ data to domestic and international ground receiving stations at 150 Mb per second using three steerable, X-band antennae. Although transmissions to international ground stations will continue, the system is being designed so that the United States can capture and refresh a global archive that will be located at the USGS's EROS Data Center. To enable ETM+ to capture data over regions beyond the range of EROS Data Center's receiving antenna in South Dakota, Landsat 7 will use a 378-Gb solid-state recorder capable of storing approximately 40 minutes, or 100 scenes, of ETM+ data. A second North American receiving station is being added near Fairbanks, Alaska, to allow 250 scenes of data per day to be collected. Thus, the recorder will downlink recorded data when the satellite is within range of either the South Dakota or Alaska station, and the EROS Data Center will receive and archive 250 ETM+ scenes per day. These features provide the capacity for global coverage of continental surfaces on a seasonal basis.

Beyond Landsat 7

The 1992 Land Remote Sensing Policy Act calls for developing cost-effective, advanced technology alternatives for maintaining data continuity beyond Landsat 7 (Sheffner, 1994). To satisfy this requirement, NASA plans to launch Earth Orbiter-1 (EO-1) as part of its New Millennium Program. This mission (see Ungar (1997), pages 901–905, in this issue) will be devoted to testing new technologies for use beyond Landsat 7. Some concepts for an advanced sensor are described by Salomonson *et al.* (1995) and Williams *et al.* (1996). In essence, advanced Landsat concepts employ solid-state, pushbroom, multispectral linear arrays, and hyperspectral area arrays that employ grating and wedge filter technologies.

Exactly how an advanced Landsat observing capability will be achieved is still under study. One option is to fly the advanced technology Landsat sensor on one of the NASA

TABLE 4. CHRONOLOGY OF LANDSAT AND LANDSAT-LIKE LAUNCHES 1972–2007. ITALICIZED ENTRIES FAILED TO ACHIEVE ORBIT, OR DID NOT FUNCTION ON ORBIT (EXCERPT FROM MORAIN AND BUDGE (1996) AND STONEY *ET AL.* (1996)).

Year	Platform (Country)	Sensor
1972	Landsat 1 (USA)	MSS; RBV
1975	Landsat 2 (USA)	MSS; RBV
1978	Landsat 3 (USA)	MSS; RBV
1982	Landsat 4 (USA)	MSS; TM
1984	Landsat 5 (USA)	MSS; TM
1986	SPOT-1 (France)	HRV
1988	RESURS-01 (Russia)	MSU-SK
1988	IRS-1A (India)	LISS-1
1990	SPOT-2 (France)	HRV
1991	IRS-1B (India)	LISS-2
1992	JERS-1 (Japan)	OPS
1993	*Landsat 6 (USA)*	*ETM*
1993	SPOT-3 (France)	HRV
1993	*IRS-P1 (India)*	*LISS-2; MEOSS*
1994	IRS-P2 (India)	LISS-2; MOS
1994	RESURS-02 (Russia)	MSU-E
1995	IRS-1C (India)	LISS-3
1996	ADEOS (Japan)	AVNIR
1996	PRIRODA (Germany/Russia)	MOMS
1997	CBERS (China/Brazil)	LCCD
1997	IRS-1D (India)	LISS-3
1998	SPOT-4 (France)	HRVIR
1998	Landsat 7 (USA)	ETM+
1998	EOS AM-1 (USA/Japan)	ASTER
1998	IRS-P5 (India)	LISS-4
1999	Resource 21 (USA)	Resource 21
2000	IRS-2A (India)	LISS-4
2002	ALOS (Japan)	AVNIR-2
2002	SPOT-5A (France)	HRG
2004	IRS-2B (India)	LISS-4
2004	SPOT-5B (France)	HRG
2004	ALOS-A1 (Japan)	AVNIR-3
2007	ALOS-A2 (Japan)	AVNIR-4

Earth Observing System (EOS) satellites, such as the AM-2 mission. Doing this would reduce launch costs. Other options include flying the sensor on a separate, smaller and less expensive, advanced technology spacecraft. A third possibility would be to see the advanced technology capabilities and Landsat continuity requirements incorporated in a commercial venture. Other papers in this issue describe the growth in capability provided by private industry that makes this option one to be considered. In any case, it is clear that the Earth science and applications communities require that the Landsat TM quality and type of data be provided and continuity ensured to preserve the integrity of the data bases inaugurated by Landsat 1. It appears clear, too, that advanced technology can be used to meet these requirements and possibly provide highly desirable enhancements.

Table 4 is a chronology of Landsat and similar international satellite systems. It lists only so-called *Earth Resources* satellites having sensors with channels roughly equivalent to those of the Landsat MSS and TM sensors. In the past 25 years there have been nearly 20 launches and four distinct international systems (a fifth, CBERS, is expected in 1997). Data from these systems are used daily by international donor agencies, government agencies at all levels, oil and mineral exploration companies, environmental consultants, value-added commercial firms, academia, and the general public. The first-order land-cover categories predictable in 1972 have grown to include rather sophisticated higher order applications. Continuity has been achieved in more than one sense (Morain and Budge, 1995). Use of time as a discriminant has been enthusiastically embraced by the user community in ways that were not foreseen, and it surely will be used in future applications in ways that are not yet perceived. Spectral analytical procedures have evolved around the time dimension and also will be stimulated by future hyperspectral data collectors. Even as the Landsat program teeters toward possible extinction, its progeny continue to nurture the vibrant technology it created.

Conclusions

The earliest visionaries, like Jules Verne, Arthur Clarke, Robert Alexander, William Fisher, Archibald Park, William Pecora, and many others, predicted great things to come as humans and their satellites ventured into space. Of all the efforts to date, the United States Landsat program ranks among the most successful. Interestingly, most of the problems that have plagued this national program have been not technical, but more administrative and political. Despite the difficulties related to national security issues, agency roles, delays in data delivery, funding uncertainties, and a shaky attempt to commercialize a federal program, its accomplishments have been extraordinary. For 25 years between 1972 and 1997, synoptic, high-quality data have been routinely acquired, processed into an ever-improving array of digital and photographic products, and used to better measure and monitor Earth resources. The Landsat series has opened new insights into geologic, agricultural, and land-use surveys, and new paths in resource exploration. An understanding of the Earth and its terrestrial ecosystems, as well as its land processes, has been advanced remarkably by the Landsat program. Of equal importance, this program stimulated new approaches to data analysis and academic research and provided opportunities for the private sector to develop spacecraft, sensors, and data analysis systems and to provide value-added services. It also has fostered strong international participation and a whole new generation of foreign-operated Landsat-like systems. The political, scientific, and commercial currents over the next 25 years of Earth-observing systems will be no easier to chart than were the first, but the systems they spawn positively advance human understanding and use of the planet's resources.

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Exhibit 4

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Exhibit 5
"Landsat Data Continuity Strategy," OSTP Memorandum of August 13, 2004

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

August 13, 2004

MEMORANDUM FOR THE SECRETARY OF STATE
THE SECRETARY OF DEFENSE
THE SECRETARY OF THE INTERIOR
THE SECRETARY OF AGRICULTURE
THE SECRETARY OF COMMERCE
THE SECRETARY OF HEALTH AND HUMAN SERVICES
THE SECRETARY OF TRANSPORTATION
THE SECRETARY OF HOMELAND SECURITY
ADMINISTRATOR, ENVIRONMENTAL PROTECTION AGENCY
DIRECTOR, OFFICE OF MANAGEMENT AND BUDGET
DIRECTOR OF CENTRAL INTELLIGENCE
ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
DIRECTOR, NATIONAL SCIENCE FOUNDATION
ASSISTANT TO THE PRESIDENT FOR NATIONAL SECURITY AFFAIRS

From: John H. Marburger, III, Director John Marburger

Subject: Landsat Data Continuity Strategy

This memorandum is to inform you of the outcome of interagency discussions to ensure the continuity of Landsat-type data observations. For over 30 years, the Landsat series of satellites has gathered multi-spectral images of the Earth's land surface and surrounding coastal regions. Landsat is a national asset, and its data have made -- and continue to make -- important contributions to U.S. economic, environmental, and national security interests. Specifically, Landsat images are the principal source of global, medium resolution, spectral data used by Federal, state, and local government agencies, academia, and the private sector in land use/land cover change research, economic forecasting, disaster recovery and relief, and the scientific study of human impacts on the global environment. Additionally, Landsat data are utilized by over 70 countries and are an important part of a global, integrated Earth observation system.

The future availability of imagery from the existing Landsat satellite constellation remains uncertain. Although Landsats 5 and 7 are currently on orbit, Landsat 5 was launched in 1984 and has far exceeded its expected lifetime, and Landsat 7 has developed a technical problem that limits the utility of the data it produces. In addition, the lack of viable commercial markets for Landsat data led to the cancellation of plans to pursue Landsat data continuity as a public-private partnership. Any disruption in the continuous availability of Landsat imagery, products and value-added services will adversely affect governmental, international, and other users and may limit use of the global data set for certain types of scientific analysis.

In order to maintain Landsat's legacy of continual, comprehensive coverage of the Earth's surface, the United States Government will transition the Landsat program from a series of independently planned missions to a sustained operational program and establish a long-term plan for the continuity of Landsat data observations. In particular, the Departments of Defense, the Interior, and Commerce and the National Aeronautics and Space Administration have agreed to take the following actions:

- Transition Landsat measurements to an operational environment through incorporation of Landsat-type sensors on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) platform, thus ensuring long-term continuity of these high-priority measurements and providing for integrated collection and availability of data from these two critical remote sensing systems;

- Plan to incorporate a Landsat imager on the first NPOESS spacecraft (known as C-1), currently scheduled for launch in late 2009. The specific implementation plan shall be jointly reviewed and approved by the NPOESS Executive Committee and Landsat Program Management; and

- Further assess options to mitigate the risks to data continuity prior to the first NPOESS-Landsat mission, including a "bridge" mission.

This NPOESS-Landsat operational strategy will need to be justified through the normal budget process. Implementation will be subject to the availability of appropriations, other applicable laws, and Presidential guidance. The cost sharing requirements of the baseline NPOESS program do not apply to the integration of Landsat into NPOESS.

These actions will ensure long-term continuity of these high-priority land, oceanic, and atmospheric measurements and will provide integrated collection and availability of data from these critical remote sensing systems for national and global applications.

Exhibit 6
"Landsat: The Next Generation," White Paper, U.S. Chamber of Commerce Space Enterprise Council

Continuity is Critical and must be maintained

It is the strong consensus of the more than twenty U.S. aerospace companies that comprise the membership of the Space Enterprise Council (SEC) that Landsat is critical and must be maintained.

Landsat has been an important part of the U.S. space infrastructure since 1972. As the longest running continuous earth imaging space program, Landsat has contributed invaluable data for agriculture, forestry, mineral exploration, global change research, education, and for the emerging commercial online mapping or GIS (Geographical Information Systems) applications. These contributions have been made worldwide as ten different countries around the world have built ground stations and developed remote sensing centers that have grown over time into remote sensing centers of excellence within their respective regions.

It is difficult to find an industry in the U.S. today that hasn't somehow been touched by the now ubiquitous GIS revolution touched off, in large part, by technologies and applications first pioneered with Landsat data. Whether planning a new coastal building, vacation or natural disaster relief, earth imaging impacts the lives of most everyone in the world.

Many of the early publications for space remote sensing and public studies using various methods for the processing and interpretation of remote sensing data were the result of both academia and industry having nearly unfettered access to the Landsat image archive.

Landsat is to earth imaging what a bridge over a canyon is to a public highway system. While it is impossible to profitably commercialize that one span of highway, it enables toll roads, local roads and interstate highways all to serve a different function in the overall transportation network. Failure to maintain that one part of the system can have detrimental impacts may have unforeseen consequences to the overall economy.

Problems encountered with previous Landsat programs were mostly attributable to attempts to widen the mission or burden it with other unrelated space monitoring objectives. The SEC believes that simplifying the procurement while also streamlining the process through a single government agency is critical. This is the best way to achieve lower system costs while ensuring longer-term mission reliability.

Landsat must remain a U.S. controlled and U.S. industry provided mission.

It is also the consensus of the SEC that Landsat remain within the jurisdictional control of the United States Government or industry and the spacecraft continue to be manufactured inside the United States.

Landsat is a "Public Good" like any other parts of the government supplied national infrastructure of this country. Just like our ports, bridges and other major infrastructure, the US public has a minimum expectation that the Landsat mission will not be surrendered to foreign ownership or control.

As the politics, economics and ultimately consequences of global environmental changes become more critical in international relations, the U.S. Government would be ill advised to become dependent on a foreign entity to ensure the calibration, accuracy and integrity of the world's most reputable source for global earth monitoring data.

While the level of contribution to global environmental changes caused by what is referred to as the human dimensions may be in dispute, the fact our earth is changing is not. Landsat is the only undisputedly credible system the world has depended on for data that now has a 30-year archive. Changing to a foreign system increases the risk that anomalies in the data really attributable to artifacts of the different instruments are misinterpreted.

As a group studying the "Landsat Pathfinder" in the early 90's correctly stated:

"There is increasing awareness that the collective actions of humanity are capable of affecting the Earth system and its processes. Humanity, in turn, is capable of being affected by changes in the Earth system induced by these effects. The nature of humanity's actions at different levels in society (local, national, and international) and in the fabric of society (for example, its social, economic, and political structures and institutions) comprise what are commonly referred to as the human dimensions of global change."

Internationally, global change is playing a larger role in diplomacy and politics as more treaties are approved that require monitoring of the impact on the global environment. More and more countries are using such information as leverage in other disputes or seeking specific economic penalties against the larger more developed countries. Putting the tools to monitor global change into the hands of other countries or even international organizations puts the system data integrity at risk and makes the US more vulnerable to foreign politicians tampering with the data set for short-term advantages.

Foreign spacecraft manufacturers are generally heavily subsidized industries if not also owned by the parent government. These subsidies are intended to increase business for the foreign manufacturers of critical space systems and also to displace the manufacturing opportunities of their U.S. counterparts. It would be especially ironic if the very system that created the 1992 Remote Sensing Act that in turn gave birth to the commercial remote sensing industry were abandoned to foreign subsidized satellite manufacturers. In this regard the US Government would be fulfilling the long-term strategic objectives of countries like India and France in displacing private US companies in the remote sensing satellite sector simply by dumping cheap subsidized systems and data onto the world market of lower to medium resolution earth imaging data.

Depending on foreign sources for future Landsat type imagery will also be contrary to the President's Remote Sensing Policy (NSPD-27) and the newly released overall Space Policy.

There is no shortage of able manufacturers in the U.S. capable of bidding a Landsat opportunity thus creating the necessary competition to keep the prices of future systems quite competitive if procured only in the U.S. Any future budgets for Landsat need to also consider the current and future costs of data acquisition from foreign systems that will be saved if there is Landsat data continuity.

Backward compatibility is key –

Don't grow Landsat into another mission. Enhanced resolutions and new technologies constitute new earth imaging missions and should not be called Landsat.

Lessons learned - Landsat cannot be made dependent on another mission or as the subset of another mission. Keeping Landsat compatible with previous data sets means compromises in the orbit, downlink, launch or other critical elements required to keep Landsat data compatible with previous data sets diminish the value of future missions.

It is in the U.S. Government's interest that radiometric calibration is well characterized. Resolutions that rival U.S. commercial systems, alternative imaging technologies (like SAR) and other advances in earth remote sensing are tempting to put onto Landsat but ultimately are not really Landsat. The continuity and feasibility (cost and schedule) of future Landsats will depend on the agency in-charge having the discipline to keep Landsat as Landsat. It is recommended that the USG migrate other earth remote sensing advances onto non-heritage type or commercial missions where they belong.

The US industry has already spent considerable resources exploring new and evolving imaging technologies that can enhance earth observation applications now using Landsat data. The SEC encourages the US Government to seek out new imaging technologies for earth sciences but simply under new programs or initiatives.

Forward compatibility is also key- the future of Landsat must be considered within the overall context of the US Integrated Earth Observation System (IEOS) and the Global Earth Observation System-of-Systems (GEOSS)

SEC member companies are very supportive of the GEOSS vision and the specific U.S. objectives described in the "Strategic Plan for the U.S. Integrated Earth Observation System." Successful implementation of IEOS (and, by extension, GEOSS) will depend heavily on the development of, and adherence to, standards and protocols for data and metadata access, interoperability, processing, dissemination, and archiving. *We believe that it is critically important that these standards and protocols be established as soon as possible, and that development of future systems such as Landsat be contingent on their adherence to the standards.*

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Exhibit 7
List of Relevant Legislation and Policies

1979 – Civil Operational Remote Sensing, Presidential Directive, National Security Council: NSC-54

1982 – National Space Policy, National Security Decision Directive: NSDD-42

1984 – Land Remote-Sensing Commercialization Act: Public Law 98-365

1988 – National Space Policy

1992 – Land Remote Sensing Policy Act: Public Law 102-555

1992 – Land Remote Sensing Strategy, National Security Presidential Directive: NSPD-5

1994 – Presidential Decision Directive, National Science and Technology Council: NSTC-3

1998 – Commercial Space Act

2000 – Amendment to Presidential Decision Directive, National Science and Technology Council: NSTC-3

2003 – Commercial Remote Sensing Space Policy

2004 – Landsat Data Continuity Strategy, Memorandum from Director, Office of Science and Technology Policy, Executive Office of the President

2005 – Landsat Data Continuity Strategy Adjustment, Memorandum from Director, Office of Science and Technology Policy, Executive Office of the President

2006 – National Space Policy

Exhibit 8
Public Workshop on the Future of Land Imaging for the United States

National Science and Technology Council
Office of Science and Technology Policy

PUBLIC WORKSHOP
ON
FUTURE LAND IMAGING FOR THE UNITED STATES

July 26, 2006
U.S. Department of the Interior
Main Auditorium
1849 C Street, NW
Washington, D.C.

MEETING SUMMARY

Contents

Meeting Summary Prepared By:
Robert J. Katt, Consultant
INFONETIC

Executive Summary

A public workshop on the future of moderate resolution land imaging for the United States was held on the afternoon of July 26, 2006, in the main auditorium of the Department of the Interior headquarters in Washington, D.C. The workshop included two panel discussions—one of representatives from the Landsat user community, the other of representatives from the aerospace industry—and a comment session open to all who attended.

The Future of Land Imaging Interagency Working Group (FLI-IWG) sponsored the workshop as part of its fact-finding and needs assessment work in preparing a long-term plan for future moderate resolution, satellite-based land imaging capability after the Landsat Data Continuity Mission (LDCM), which is now in procurement. A December 2005 memorandum from the Director of the Office of Science and Technology Policy called for a study to identify future needs and options for U.S. land imaging and named the FLI-IWG, which reports to the National Science and Technology Council, to conduct the study. The workshop opened with a report on the Working Group's preliminary findings and its plans for preparing the long-term plan by February 2007.

The panel presenting views from the user community on Landsat data included two members representing private-sector end users of information derived from Landsat data, two commercial value-added resellers, two users from the nonprofit sector, and one representative of State and local public-sector entities. Kass Green, Vice President of the American Society for Photogrammetry and Remote Sensing (ASPRS) moderated the panel and presented preliminary findings from an ASPRS survey of users' views on future land imaging capabilities. The private sector end users described their reliance on Landsat data for legal expert witness testimony in Federal and State courts and for risk management in the insurance, finance, and health industries. Wildlife conservation and resource management is the focus of one of the nonprofit users; the second relies on Landsat data to determine the extent and consequences of deforestation in the Andes-Amazon basin. One of the value-added resellers primarily serves the Federal defense/intelligence and civil agency markets; the other uses Landsat data for commercial land cover mapping and analysis required by State and local entities and by commercial companies. Among State agencies with responsibilities for resource use or management, Landsat data consistently rank in their top five data needs. Preliminary ASPRS results show that 69 percent of the responders use Landsat data as their primary source of moderate resolution data.

The representatives of the U.S. aerospace industry on the second panel described their corporate capabilities in Earth-observing spacecraft and sensing instruments and their views on trends in future instrument capability and applications development for land imagery. The trades necessary between increasing capability and cost were discussed, as were issues in program continuity, program governance and management, lessons learned from the Landsat experience, and the current global environment for satellite-based sensing and imaging beyond current Landsat or anticipated LDCM capabilities.

During the public comment session, a recurring theme was impatience with the delays and erratic progress toward creating an operational moderate resolution land imaging program, even though such a program has been stated as a National policy since at least 2004. All open-session comments, as well as all views on the subject expressed by panelists, favored a single Agency lead for the future land imaging program.

The public comments ranged between advocates of a no-cost data policy for moderate resolution land imaging supported by public funds, similar to the data provided by the NOAA National Weather Service, and those who argued for a privatized capability on a cost-recovery fee basis, albeit with U.S. Government backing of unspecified degree and form. The affordability of Landsat data was frequently cited by the user panelists as an essential factor in the mushrooming expansion and diversification of applications in all sectors. The moderator of the second panel, reflecting on the extent and characteristics of the applications described during the first panel, estimated the total economic value of just the current applications as being at least in the billion-dollar range, if not worth tens of billions to the U.S. economy.

Acronyms

AIAA	American Institute of Aeronautics and Astrophysics
ASPRS	American Society for Photogrammetry and Remote Sensing
AVHRR	Advanced Very High Resolution Radiometer
DOD	U.S. Department of Defense
DOI	U.S. Department of the Interior
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EPA	U.S Environmental Protection Agency
ERTS-A	Earth Resources Technology Satellite A
FBI	Federal Bureau of Investigation
FEMA	Federal Emergency Management Agency
FLI-IWG	Future of Land Imaging Interagency Working Group
GEOSS	Global Earth Observing System of Systems
GIS	geographic information system
GPS	Global Positioning System
IEOS	U.S. Integrated Earth Observation System
LIDAR	Light Detection and Ranging
LDCM	Landsat Data Continuity Mission
MAPPS	Management Association for Private Photogrammetric Surveyors
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Adminsitration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NSGIC	National States Geographic Information Council
NSTC	National Science and Technology Council
OSTP	Office of Science and Technology Policy
USDA	U.S. Department of Agriculture
URISA	Urban and Regional Information Systems Association
USGEO	U.S. Group on Earth Observations
USGS	U.S. Geological Survey
VAR	value-added reseller
VIIRS	Visible/Infrared Imager/Radiometer Suite

Exhibit 8

Public Workshop on Future Land Imaging in the United States

U.S. Department of the Interior
Washington, D.C.
July 26, 2006

Introductory Remarks

Gene Whitney of the Office of Science and Technology Policy (OSTP) opened the workshop. Dr. Whitney is the National Science and Technology Council (NSTC) liaison to the Future of Land Imaging Interagency Working Group (FLI-IWG), which is the sponsor for this public workshop. He introduced the chair of the workshop, Timothy R. Petty, Deputy Assistant Secretary for Water and Science in the Department of the Interior (DOI).

After introducing the two panel moderators, Mr. Petty described the membership and work of the FLI-IWG. Future capabilities in land imaging are important to the Nation, Mr. Petty said, because the scientific determinations from imaging data support better policy decisions with respect to land use and land management, agriculture, and a myriad other aspects of the missions of participating Federal agencies. He reviewed the history of DOI's involvement in land imaging, noting that the Landsat system is now operated under the U.S. Geological Survey (USGS). The general topic for discussion today is how to build upon and continue to grow this national asset in land imaging.

The Future of Land Imaging Interagency Working Group

Dr. Whitney asked the members of the FLI-IWG to introduce themselves. He gave a brief overview of the process that the FLI-IWG has used and the directions in which it is heading. The objective of this meeting is for the Working Group members to listen to comments from the stakeholders and communities of interest represented on the two panels and in the audience. He emphasized that this meeting is not about the Landsat Data Continuity Mission (LDCM), which is currently in procurement. That procurement activity is a separate process from planning for the future of land imaging beyond LDCM, which is the topic of this workshop. The purpose of the FLI-IWG is to develop a stable, long-term management and funding situation for U.S. land imaging.

Dr. Whitney described the swath width and resolution characteristics typical of moderate-resolution satellite-based land imaging, in the context of the full panoply of tools and techniques for land observations, including in situ and airborne sensing as well as satellite-based sensing from the lower resolution instruments of VIIRS (Visible/Infrared Imager/Radiometer Suite) and AVHRR/MODIS (Advanced Very High Resolution Radiometer/ Moderate Resolution Imaging Spectroradiometer) to the higher resolution of commercial systems. The FLI-IWG working concept for moderate resolution land imaging has used a range in spatial resolution of roughly 10 m to 120 m. Dr. Whitney presented illustrative lists of uses for land imaging in this range and the societal benefits from them. However, he emphasized that these lists were partial, and hearing about current and potential uses of moderate resolution land imaging from users was a principal workshop objective.

Next, Dr. Whitney reviewed the policy history of U.S. satellite-based land imaging, beginning with the launch of the first Landsat—Earth Resources Technology Satellite A (ERTS-A)—in July 1972 and continuing through the Land Remote Sensing Policy Act of 1992 and the subsequent unsuccessful attempt to establish a public-private partnership to provide Landsat data continuity. He summarized the major implications for Landsat policy of the OSTP memoranda on Landsat strategy of August 2004 and December 2005. In particular, the December 2005 memorandum revised the earlier strategy of including a Landsat instrument in the instrument suite for the National Polar-orbiting Operational Environmental Satellite System (NPOESS), in light of the design complexities that had emerged. Both memoranda set a goal of transitioning Landsat from a series of independently planned missions to a sustained operational program funded and managed by the U.S. Government. The December 2005 memorandum also called for a study to identify future needs and options for U.S. land imaging, to be prepared by the FLI-IWG. The FLI-IWG takes the section of this memorandum on "Ensuring long-term continuity" as the charter for its work. (Full text of the OSTP memorandum is available at http://www.landimaging.gov/12-23-2005.pdf.)

For the past two months, and continuing with this workshop, the FLI-IWG has been conducting fact-finding, analysis, and needs assessment. The Working Group anticipates release in February 2007 of a long-term plan for a moderate resolution land imaging capability, in accord with the goals and objectives of the U.S. Integrated Earth Observation System (IEOS). In addition to this workshop, interested parties can provide input to the process by email (mailto:survey@landimaging.gov) or by responding to a survey on the future of land imaging, sponsored by the American Society for Photogrammetry and Remote Sensing (ASPRS) and available on the ASPRS website (http://www.asprs.org/).

Dr. Whitney presented the FLI-IWG's findings to date on characteristics required for moderate resolution land imaging, calibration of data over time to a national standard to maintain continuity in the land data record, and the necessity of frequent synoptic coverage of the entire Earth. Backward compatibility with the U.S. land data record is a requirement, but future land imaging capabilities need not be limited to Landsat capabilities. A major Working Group task is to tie required technical capabilities back to the societal benefits of land imaging and how they can best be achieved. Among these benefits are the societal benefits defined for IEOS and the international effort know as the Global Earth Observing System of Systems (GEOSS):

- Weather
- Natural disasters
- Ocean resources
- Climate variability and change
- Human health

Exhibit 8

- Ecological forecasts
- Agriculture and forestry.

A further set of societal benefits go beyond the GEOSS and IEOS goals, but are important to meet U.S. economic and national security interests. Among these are:

- Land use planning and management
- Public lands conservation and management
- National security operations
- Transportation planning and management.

The best long-term solutions for operational land imaging capabilities to meet national needs traceable to these benefits may vary over time, so proposed solutions should be flexible. The Working Group anticipates that Government-owned satellites will be the near-term data acquisition solution, combined with a complementary international partnership. Other options being considered for the future include public-private partnerships, international partnerships, a commercial program, and combinations of these approaches. With respect to the management and governance structure overseeing the satellite operations, options under consideration include a single Federal agency responsible for all aspects of land imaging, a multiple-agency structure in which responsibilities are shared, an integrated program office reporting to multiple Federal agencies, a national commission to manage the land imaging program, or a purely commercial or international manager with no Federal agency having responsibility for management or oversight.

Multiple Federal agencies have shared responsibilities for operating Landsat satellites. The process for developing each new satellite has been ad hoc. Each agency also interacts independently with potential partners in the academic community and the private sector (e.g., value-added resellers). The FLI-IWG believes that focused Federal leadership of the land imaging community is essential. Although the land imaging enterprise is too large and complex to be conducted entirely by a single agency, a lead agency is necessary. A designated Federal lead agency can provide unified planning and responsibility for operations. It should have responsibility for coordination among agencies on land imaging needs; data acquisition, quality control, and distribution; and acquisition of technology and systems. The lead agency would serve as a single point of contact for non-governmental users and contractors, as well as for international partners and international negotiations. The management/governance structure must also provide a point of accountability for performance, while allowing for flexibility in leadership as technical, fiscal, and political factors change. The Working Group thus envisions a National Land Imaging Program with a designated lead agency and a coordinating board with members from each of the agencies participating in the program. An option under consideration is to designate DOI as the lead agency, perhaps with management of the program at the assistant secretary level. DOI has sent a letter to OSTP expressing its interest in such an arrangement. The national program would be a coordinating program and would not subsume the existing land imaging programs of the partnering agencies. Dr. Whitney described how this coordinating role might work with respect to other major

Federal initiatives including the U.S. Group on Earth Observations (USGEO) and GEOSS, the programs and projects of individual Federal agencies, and land imaging activities in the private sector.

In closing Dr. Whitney encouraged responses to the ideas and options he had presented. Further information on the FLI-IWG is available on its website (www.landimaging.gov), and views can be emailed to survey@landimaging.gov. He also asked participants to send anecdotes showing the value of land imaging, any qualitative information or quantitative metrics about the value of land imaging in particular sectors, and thoughts on trends in land imaging that may be emerging on the horizon.

Panel 1: Views of the User Community on Future of Land Imaging

Kass Green, moderator for the first panel, thanked the DOI for offering a home for a land imaging coordination program. She thanked the panelists for taking time to participate and the FLI-IWG for their efforts to date, then introduced the panelists and their current affiliations (see box). This panel includes two members from the value-added reseller (VAR) community, two members representing end users of information from the imagery, two users from the nonprofit sector, and one representative of State and local public-sector entities.

Panel 1: Views of the User Community

Kass Green, *Moderator*, President of Alta Vista Company and Vice President, ASPRS
Susan Carson Lambert, past President, National States Geographic Information Council
Jim Schriever, Senior Vice President, Sanborn Solutions
John Brown, President, Aircorp
Doug Hall, President and CEO, MDA Federal
Jennifer Swenson, Andes-Amazon Project Manager, NatureServe
Dan Ferhringer, GIS/Remote Sensing Manager, Ducks Unlimited
William Raichle, Vice President for Risk Decision Information, ISO, Inc.

Preliminary Results from the ASPRS Survey

Ms. Green began with a summary of the goals, background, and preliminary results to date from the ASPRS survey on the future of moderate resolution land imaging. The goals are to: (1) estimate the societal benefits of U.S. moderate resolution data, (2) better understand current operational and research uses of moderate resolution data, and (3) identify user requirements in moderate resolution technology and data policy. The survey questions were created and reviewed by a team of professionals with input from the FLI-IWG. An email blast requesting responses from their members was sent out by the ASPRS, the Management Association for Private Photogrammetric Surveyors (MAPPS), the Urban and Regional Information Systems Association (URISA), the National States Geographic Information Council (NSGIC), and other entities that maintain email pointcasting lists. As of July 25, the survey, which was first posted on July 5, had 914 respondents from around the globe. The respondents are about equally divided among academic, commercial, and governmental affiliations. The majority of respondents (69 percent) use Landsat data as their primary source of moderate resolution data, 46 percent work in an operational program, and 73 percent stated that Landsat is a primary, critical dataset for their applications. Many of the respondents' programs that use Landsat data were established decades before the first Landsat launch; these programs have incorporated Landsat-derived information as it became available. The

Exhibit 8

varied nature of these operational programs is illustrated by the list in table 1, drawn from the survey responses received to date.

Table 1. Operational Programs Currently Using Moderate Resolution Land Imaging Data

Carbon cycle monitoring	Mineral exploration
Coastal change analysis	Monitoring grant performance
Crop estimates	Range management
Deforestation monitoring	Recreation planning
Design of defense systems	Snow and ice monitoring
Detecting and monitoring volcanic activity	Soil analysis
Ecosystem mapping	Space cartography
Emergency response	Support of DOD operations
Forest management	Water resource planning and administration
Invasive species monitoring	Water rights monitoring
Inventorying toxic releases	Weather prediction
Irrigation management	Wetlands rehabilitation
Land use and land cover change	Wildland fire risk assessment
Mapping groundwater discharge zones	Wildlife reintroduction

Ms. Green characterized the preliminary data as confirming that a Landsat data gap is already being felt by users. Of the respondents who expressed an opinion about Landsat, 81 percent stated that current Landsat 5 and 7 data do not meet all of their needs, given the current scan line corrector problems of Landsat 7 and the coverage limitations of Landsat 5. Approximately 78 percent of the same respondents stated that, if the scan line corrector failure on Landsat 7 had not occurred, Landsat 7 data would have met their current needs. In order of importance, the top five reasons cited by respondents for using Landsat data rather than other remote-sensing data were that: (1) Landsat data are more accessible; (2) a large Landsat archive exists, containing over 30 years of consistent data; (3) Landsat data are relatively less expensive; (4) Landsat data provide more repetitive coverage; and (5) the extent of Landsat scenes is most appropriate for the respondent's project. Ms. Green highlighted survey results that indicate the quantitative impacts to users if Landsat service were lost. With respect to increasing the utility of moderate resolution imagery, the top five factors for these respondents were (in order of importance) greater spatial resolution, lower-cost data, more frequent temporal coverage, more spectral resolution, and easier access to data.

The survey analysis will include quantitative data on the spatial resolution (in meters) and temporal resolution (in days between re-imaging) desired by respondents, as well as the strength of respondent opinions (from full agreement to strong disagreement) on a set of survey questions regarding management and ownership of land imaging services, the role of the Government, and directions for expanding imaging capability. These quantitative results will be complemented with quotes extracted from individual responses to illustrate the range of applications, societal benefits, and criticality of moderate resolution imagery like that provided by Landsat. Ms. Green's presentation slides included preliminary quantitative analyses from the responses received through July 21, plus a selection of quotes.

Mapping Ecosystems and Deforestation Impacts in Developing Countries

Jennifer Swenson of NatureServe described the range of services performed by this nonprofit network and then focused on how her Andes-Amazon Project is using Landsat vegetation data to map ecosystems and deforestation in South America. Of the 80 Landsat scenes available for Peru, her project is using about 40. About 105 ecological communities will be mapped. Landsat provides a combination of regional coverage with the details needed to perform this ecological mapping and determine the extent and consequences of deforestation. Landsat's repeat coverage is valuable because of the frequent cloud cover in this region, and the data are affordable enough to allow continuous updating. The historical coverage is essential to showing land use changes over time. Any application involving vegetation mapping or ecosystem monitoring in developing countries, such as Peru, is highly dependent on Landsat to provide the base layer mapping, because of the dearth of ancillary data to map the ecosystems.

Wildlife Habitat Conservation Management

Dan Ferhringer described how Ducks Unlimited uses moderate resolution imagery to manage individual wildlife habitats all along the major continental flyways for migratory waterfowl. The combination of full Western Hemisphere coverage and adequate spatial resolution is essential for these applications, which have included mapping of boreal forests in Canada; the prairies, Great Lakes, and Missouri-Mississippi Valley in the United States, and habitats in Mexico, Central America, and South America. The interpreted imagery products that Ducks Unlimited and its affiliated organizations produce allow them to set priorities and make the best use of their limited resources. The products are also used in their work with Federal, State, and foreign governments on conservation and wildland management priorities, with agricultural and forestry companies on land resource management, and with nongovernmental organizations. Mr. Ferhringer gave examples of activities and programs that have been supported with his habitat analysis products, together with the societal benefits from these activities.

Value Added Products Supporting Defense and Civil Agency Missions

Doug Hall of MDA Federal (formerly Earth Satellite Corp.) said that his company has been processing Landsat data since the early 1970s. The company's clients include 13 agencies and organizations in the Department of Defense (DOD) and the intelligence community; multiple entities within the DOI, Department of Commerce, and Department of Agriculture; the U.S. Environmental Protection Agency (EPA); the Federal Emergency Management Agency (FEMA) in the Department of Homeland Security, the National Aeronautics and Space Administration (NASA), and entities in State government and the private sector. The combination of comprehensive coverage at regional to national scales and moderate resolution is essential to many of the applications MDA Federal supports, including those shown in table 2. Although MDA Federal also works with high-resolution data from both defense/intelligence sources and the private sector, Mr. Hall emphasized that those datasets complement, rather than replace, the role of moderate resolution imagery such as Landsat provides. Recent projects illustrated in the presentation slides included land use change detection on the Gaza-Egypt border and

Exhibit 8

illicit crop inventory (opium poppy cultivation) in one province of Afghanistan. Another recent project compared the areas of the Indian Ocean affected by the December 2004 tsunami with pre-tsunami scenes, to highlight alterations of coastline and underwater hazards. In closing, Mr. Hall stressed the need for an operational moderate resolution land imaging capability to support Federal agency activities.

Table 2. Value-Added Applications of Moderate Resolution Imagery to Support Federal Missions

Civil Agencies	DOD/Intelligence Community
Land cover mapping	Change detection
Change detection/monitoring	▪ Intelligence tip-offs
Disaster response	▪ Monitoring
Humanitarian relief	▪ Map updating
Geologic mapping	Illicit crop assessment
Forestry assessment	Food security
Agricultural assessment	Land cover mapping
Wetlands mapping	Shoreline/hazards mapping
Fire risk assessment	Infrastructure mapping
Impervious surface mapping	
Environmental monitoring	

Source: MDA Federal

Applications Used by State and Local Governments

After an overview of her career as a land surveyor, cartographer, and geographer with the USGS and as a principal investigator for state projects in Kentucky, Susan Carson Lambert said that the States are major users of Landsat data. She urged the FLI-IWG to ensure that the views of State agencies and offices are surveyed. From a much larger set of applications that her contacts in State and local government had sent her, she presented the representative, but partial list of applications shown in table 3. After describing details for several of the listed applications as they are used by State and local entities, Ms. Lambert stressed that all of these applications represent mandated activities required of State and local governments.

In a study Ms. Lambert conducted of non-Federal public sector needs for data, Landsat data and moderate resolution imagery were in the bottom quartile (lowest 25 percent) for the entire range of public sector entities. However, for State agencies with responsibilities for resource use or management, Landsat data were always in the top five data needs. Another difference is that entities in states east of the Mississippi often wanted imagery with higher resolution than Landsat, whereas states west of the Mississippi, where the land areas to be monitored or managed are much larger, are typically content with the current Landsat resolution and use the products routinely. She has also observed that the extent to which State entities make use of imagery data and products often depends on their interactions with Federal counterparts, who show them how the data and products can be used.

Table 3. State and Local Applications of Moderate Resolution Imagery Data

Agricultural field crop health
Comprehensive plan efficacy monitoring
Crop insurance verification
Forest canopy mapping
Forest fire scar mapping
Forest fire susceptibility mapping
Forestry composition and forest composition change
Imperviousness mapping
Insect damage mapping i.e. pine beetles
Invasive species mapping
Land cover change analysis

- Comprehensive plans
- Logging effects
- Mining effects
- Efficacy of mine reclamation

Land management decisions
Mineral exploration (State geologic surveys)
Modeling of rock formation
Preliminary analysis for logging species
Rangeland health and change
Riparian zone mapping
Risk management for post-forest fire stream silting, mud slides & erosion and mud-slides
Sensing of lava flows
Water quality analysis
Watershed analysis for modeling

- Modeling watershed capacities
- % development before ecosystem damage

Wetland mapping
Wetness/drought analysis
Wildlife management
Wildlife habitat analysis

Exhibit 8

For non-Federal public sector entities, Ms. Lambert said in closing, the benefits of Landsat products are that they are affordable and shareable (e.g., among State agencies and from them down to local entities); the bands are usable by many applications these entities have, there is a great deal of supporting science behind the data (algorithms, classification, indices, etc., that can be applied); there is a long period of record for applications such as land use change over time; and Federal agencies support the State and local entities with best practices for using and interpreting Landsat data. The principal downside she hears from colleagues in these entities is that they want higher resolution.

Applications of Landsat Imagery in Legal Proceedings

John Brown is President of Aircorp, which stands for Agricultural Investigation Research Corporation. He described applications of Landsat data in his work as a legal expert witness in Federal and State courts. One example is agricultural fraud detection related to loss claims made under the crop insurance program of the U.S. Department of Agriculture (USDA). He also uses Landsat data as evidence of the impact of human activities on property and land resources, in investigations of water sources and water rights, and for detection of water leaks from pipelines. Clients include the Risk Management Agency in USDA, the U.S. Department of Justice, insurance companies, and local governments.

Among the societal benefits that Mr. Brown sees from his company's uses for Landsat data are fraud detection, finding and ensuring appropriate use of water resources, reducing exposures to chemicals and pesticides, and crop development (precision farming). Another set of benefits relate to detection of the impact of disasters such as Hurricane Katrina, including facilitation of rescue (for example, farm animals) and recovery and for quantifying damages for purposes of compensating for losses.

Important characteristics of Landsat data for legal proceedings are its reasonable cost, ease of access, the extensive historical archive (going back to 1972), and its established record and wide acceptance in the scientific community (proven technology). Ease of access is important because court deadlines are demanding; there are no excuses for failing to meet a Federal court deadline. Although Aircorp's range of applications could use higher resolution, Mr. Brown finds that 30 m resolution is workable. The multi-band algorithms are very important for his work. In addition to the data's established scientific basis, acceptance in court proceedings is aided by the documented chain of custody of the data and the reliability of the data protocols. Mr. Brown also finds that basic analysis techniques for Landsat data are easily taught to clients.

Commercial Land Cover Mapping

Jim Schriever began with a brief history of Sanborn, where he is Senior Vice President of the Sanborn Solutions division. The company was started in 1866 by a Civil War cartographer and initially produced detailed city maps for fire insurance companies. Sanborn still provides subscription mapping services. In addition to its applications of satellite imagery, the company owns a fleet of aircraft with digital and analog airborne sensors and LIDAR for high-resolution mapping products and services. In the moderate resolution area, Landsat is their "workhorse" observing system, although they also use commercial satellite imagery. Mr. Schriever views Sanborn's regional presence, with offices located in a number of states, as an important asset when working closely with clients on applications that are pushing the limits of imagery interpretation. Sanborn's land cover mapping philosophy emphasizes the capability needed not just for imaging, but to put the image data to use. Consistent core funding for some of the baseline applications of Landsat data, he said, is critical for putting that data to work. Coordination of collaborations among State and local public sector entities, Federal agencies, and commercial partners is central to this philosophy. Sanborn has been able to leverage the investment of Federal resources with State resources to the extent that State partners have provided up to $10 in funding for every $1 of Federal funding. Across the board, Sanborn has been able to coordinate partnerships to at least match the Federal contribution, dollar for dollar, with State money.

Other tenets of Sanborn's philosophy are attention to data quality and consistency and the capacity to deliver cost-effective, timely solutions to customers. To illustrate how quality and consistency apply to Landsat data, Mr. Schriever described the successful application of 30 m resolution data to mapping of wildfire fuels in Florida, where better than 90 percent accuracy was achieved. Moderate resolution imagery is often key to providing a timely and cost-effective solution, compared with the prohibitive cost and schedule time required for regional-scale mapping with high resolution datasets. Examples Mr. Schriever cited were species-specific habitat maps of the entire West Coast, produced within 9-12 months to meet requirements of the Endangered Species Act. Land cover mapping applications for which moderate resolution imagery provides cost-effective, timely solutions of high quality include the following:

- Fire risk management (e.g., fuels and canopy closure analyses)
  - Fire susceptibility indices are being used in 15 states.
  - Datasets for the National Landfire Program will be based on 2001 imagery.
  - Community Wildfire Protection Plans (CWPP's) for communities at high risk of wildfire losses will probably need higher-resolution data added to a state-level synoptic view.
- Consistent national datasets (time series) are essential to establish historical baselines needed for:
  - Trend analysis
  - Change detection.
- Global crop analyses
- Cumulative effects analyses
  - First approximation reports
  - Response to requirements under the Endangered Species Act
- Monitoring outbreaks of insects and diseases

In his closing slide, Mr. Schriever presented and discussed an analysis developed for the American Forest Organization. Time series images from the USGS National Land Cover Dataset are used to analyze land cover changes, which in turn can be linked to quantitative changes in tons of air pollutants removed by forested areas, tons of carbon sequestered in biomass, amounts of water retained in soils rather than lost to runoff, and other ecosystem factors. Without the Landsat sensors and the data they provide, such analyses would not be possible.

Risk Management Applications for the Insurance, Finance, and Health Industries

William Raichle described the work of his company, ISO, as helping customers measure, manage, and reduce risk. Its products help customers identify, mitigate, and price for risk by providing them with data, analytics, and decision-support services. The information Mr. Raichle presented about ISO's business is also available on its website at http://www.iso.com/about_iso/. Part of ISO's business is to collect premium and loss data for commercial insurance transactions and to help insurance companies determine loss cost for their business lines. For example, ISO promulgates the fire suppression schedules for firefighting entities across the Nation. These schedules are used in setting property insurance rates. ISO also maintains databases on commercial properties for purposes of insurance underwriting. Its insurance claimant database is used by the insurance industry and the Federal Bureau of Investigation (FBI) to detect insurance fraud.

ISO maintains the largest geographic information system (GIS) in the insurance industry, containing 25 database products. One of the databases that depends on satellite imagery is FireLine, which contains information on the wildfire hazard for purposes of property insurance. Although not a major fire loss risk, wildfire losses are significant for the industry and they are increasing. From 1985 to 1994, wildfires destroyed more than 9,000 properties nationwide, including the 2,449 dwellings destroyed in the Oakland/ Berkeley Hills fire of October 1991, causing an estimated $1.5 billion in damage. A decade later, the southern California firestorms in October 2003 destroyed 3,400 structures and caused more than $2 billion in insured property losses. The FireLine database, which uses Landsat data for its "Fuel" layer, grew out of the inadequacy of more traditional hazard mapping methods to cover large regions. Once interpreters with sufficient expertise with the Landsat data were found, ISO was able to identify and assess the urban-wildland interface consistently and reliably with a cost-effective program. For example, 97.5 percent of the burned area from the 2003 southern California fires had been identified in the FireLine database as exposed to a wildfire hazard, and 95.7 percent of the homes affected by those fires had been identified as exposed. Insurers prefer to base ratings on data from a shared, accurate, and consistent source, such as Landsat data, rather than on proprietary data or conflicting interpretations.

Panelist Responses to Questions on Future Land Imagery Planning

After Mr. Raichle's presentation, Ms. Green asked the panelists what they thought was the most important thing the FLI-IWG needs to know about user needs for future moderate resolution land imagery.

Doug Hall said that imagery and data from sources representing a range of resolutions will be necessary. Although a commercial industry supplying high-resolution land imagery and data is emerging, that alone will not meet all users' needs. He also said there are frequent misperceptions about the source of value-added imagery products offered by VARs, when their data originate from Landsat data.

Jennifer Swenson stressed the importance of international applications for moderate resolution imagery. The low expense, comprehensive coverage, and other attributes of the Landsat data are even more critical in other countries that lack access to any alternatives for many of the applications enabled by moderate resolution satellite imagery.

John Brown said the most important thing for him were the benefits to the American farmer. Modern farming requires this kind of moderate resolution, inexpensive, and dependable data. Increasingly, farmers use such data to conserve energy, lessen environmental damage, and protect their crops. A weekly interval for re-imaging would be important to farmers, but the most important qualities are dependability and reliability.

Jim Schriever agreed with points the previous speakers had made and added that continuity of land data over time, building on the Landsat heritage, was important for many applications. In addition to Federal support for imaging and image archiving, Federal support for a land mapping capability through an operational, continuously funded program is important to realize the potential benefits of the multitude of applications.

Susan Carson Lambert also agreed with the points the other panelists had stressed. She emphasized that U.S. cities and its 3,300 counties and parishes need the data provided by moderate resolution land imaging. The program must maintain accessibility of the data and its backward compatibility with the historical data. In addition, some basic products for change analysis would be useful to those public sector entities that cannot afford to undertake the required analysis themselves.

William Raichle's suggestion for the FLI-IWG was to get to know the end users, even beyond this workshop. The better that those involved in changing the land imagery program know users and their needs, the better received the inevitable changes will be in the user communities. Another reason to get to know the user communities is to avoid duplication by the Government of services that VARs are providing.

Dan Ferhringer said that, for the nonprofit organizations, the cost of the basic data is always an important consideration. As others had emphasized, continuity of the data is essential because of the importance of change analysis for land stewardship and responsible resource management.

Panel 2: Views of the U.S. Aerospace Industry on Future of Land Imaging

Major General Bob Dickman (U.S. Air Force, retired), the moderator for the panel representing the U.S. aerospace industry, is currently the Executive Director of the American Institute of Aeronautics and Astrophysics (AIAA) and formerly the Deputy for Space in the Office of the Undersecretary of the Air Force. In introducing the panel topic, Gen. Dickman said that the OSTP memorandum of

Panel 2: Views of the Aerospace Industry

Maj. Gen. Bob Dickman (USAF, retired), *Moderator*, Executive Director, AIAA
James Good, Director of OS Program Development, Ball Aerospace
Robert LeRoy, Director of East Coast Operations, Civil Space Systems, Lockheed Martin Space Systems Company
Ron Birk, Director of Mission Integration, Northrop Grumman Space Technology
Satya Kalluri, Senior Engineer, Raytheon Corporation

Exhibit 8

December 2005 made clear the Administration's commitment to the transition of U.S. land imagery capability to an operational program. The path forward and the mechanism to accomplish this transition is less clear, he said. He urged all stakeholders with an interest in such a program to remain engaged in working toward a program that is implemented and consistently funded. In his view, the annual economic value of all the downstream applications described by the previous panel, including both direct benefits and indirect ramifications, is probably at least in billions of dollars and perhaps in the tens of billions.

Lockheed Martin

Robert LeRoy of Lockheed Martin was previously Chief Engineer and then Program Manager for Landsat 7 and has 15 years of involvement in Landsat programs. His talk covered current capabilities in remote sensing, the meaning of the land imaging mission today and in the future, and some lessons learned from the company's past experience with Landsat. The U.S. aerospace industry has demonstrated the capability to deploy a diverse set of land remote sensing missions, covering high-resolution, broad area coverage, multispectral, hyperspectral, and other sensing modalities for military, civil, commercial, scientific, and national security applications. As the supporting technologies in solid state electronics, communications, and spacecraft navigation have improved, the range of potential mission types and characteristics has multiplied. The industry knows that a wide range of potential customers and application needs to be served and has made substantial investments in remote sensing technologies, as illustrated by Mr. LeRoy's chart of sensor wavelengths covered by remote sensing missions.

Because the Landsats have had overlapping operating lives, the community has been able to provide cross-calibration across the succession of satellite and observing instrument generations. However, to ensure reliability of coverage and historical continuity across satellite generations in the future, a program is needed that plans for and maintains more than one satellite in orbit at a time. For example, the LDCM will introduce new technology with improved performance, which will require cross-calibration and validation with previous data.

Mr. LeRoy offered the following set of lessons learned from Lockheed Martin's work with past Landsats:

- There is no substitute for close cooperation between data users and system builders. Ongoing dialogue is needed on what can be provided within specified cost and other constraints, weighed against the needs to be met.
- Early agreement and a freeze on requirements are essential to control cost and schedule.
- Program schedule and cost depend on the execution of all program elements; including satellite, instrument, ground segment, and launch vehicle.
    - Systems engineering needs to be an integrated effort across the entire system.
- Risk must be carefully assessed for all program elements when defining the system.

  - Low-risk development requires much more than the use of flight heritage hardware and software.
- For operational deployments, instrument development cannot proceed independent of spacecraft development.
- Complete transparency within the government-industry team spells success.

In closing, Mr. LeRoy said that a future land imaging program will have to define and balance the needs of spatial and temporal resolution with spectral and radiometric characteristics. The U.S. and foreign governments will remain the primary customers, and the aerospace industry can help customers define what is technically possible. Finally, the lack of program continuity does impair the industry's ability to provide cost-effective solutions.

Ball Aerospace and Technology Corporation

James Good began by noting that Ball Aerospace and Technology Corporation has participated in all of NASA's Great Observatory missions and became involved with Landsat through its role in commercial land imaging satellites in the 1990s. Ball was a member of both the first Resource 21 team venture for agricultural imaging, which failed for lack of investor interest, and the Resource 21 team in the unsuccessful commercialization approach to LDCM. Mr. Good emphasized that starts and stops in such programs are difficult for all players. The engineering and requirements analysis required to pursue a bid are a major investment for the offerors, and customer commitment to an operational system is necessary to avoid squandering both industry and Government funds.

Ball believes that U.S. industry is fully capable of implementing a base mission using affordable, low-risk technology and providing capabilities well beyond what is currently being requested for Landsat. Most of the capabilities mentioned during the user panel are certainly available and affordable, such as 5-10 m resolution. By the time a procurement is released for whatever the future land imager will be, the industry and the enabling technologies will be another 4-7 years further developed. With respect to keeping land imaging technology moving forward, Mr. Good stressed the importance of flight demonstrations for each new generation of instruments. To provide continuity as capabilities grow, he suggested that new technology be flown on missions every 5 years or so.

Raytheon Company

Satya Kalluri began with a review of remote sensing instruments built by Raytheon for NASA Earth Observing System (EOS) missions, its work on the EOS Data and Information System (EOSDIS), and the Synergy program to develop EOS applications for Federal, State, and local agencies. The Synergy program, which NASA initiated in 2000, has six major themes: precision agriculture, natural resource management, disaster management, water resource management, urban planning, and disease mitigation. Dr. Kalluri listed some of the Federal, State, and local entities that have been Synergy partners and described in detail several applications of EOS data developed for them. Among these applications are water use monitoring for the Idaho Department of Water Resources and precision agriculture for a group of wheat farmers in North Dakota. Dr. Kalluri suggested the following requirements for moderate resolution land data:

- Frequent coverage
  - Weekly—natural resource management (e.g., agriculture, water resources) and disaster mitigation
  - Every two weeks—land cover monitoring
- Low cost
- Ability to share data without copyright restrictions
- Data continuity, longevity, and reliability
- Standardized data formats and content
- Operational acquisition strategy.

Users have a wide choice of moderate resolution satellite data for land applications, but reliable alternate sources of data to Landsat have not been demonstrated for sustained, operational use in applications within the United States. Wider application from the full range of sensor types and data suppliers (including foreign-owned satellites) has been hampered by the following barriers:

- Data incompatibility from different sensors makes analysis of long-term trends difficult.
- Restrictions in data sharing and copyrights on non-U.S. government data impede their widespread adoption and use.
- Users are unwilling to adopt "experimental" data in their operational business practices.

Therefore, Dr. Kalluri concluded, we must establish a long term data continuity plan for operational acquisition and use of moderate resolution land imaging data.

Northrop Grumman Space Technology

Ron Birk of Northrop Grumman Space Technology began his career building Landsat simulators. He noted NASA missions to which Northrop Grumman has contributed, including the Aqua and Aura spacecraft, NPOESS, and the telescope for the Space Interferometry Mission (SIM). He emphasized the importance of space-based capability and assets in enabling many aspects of an information society's infrastructure. Economics is now the major driver for maintaining and enhancing space-based assets for communications, navigation, and observing. Continuing technological advances in space-based sensing is increasingly important to U.S. competitiveness. A consistently resourced program to sustain and improve U.S. capabilities in areas such as satellite-based land imaging is more efficient and cost-effective than stop-and-go approaches.

While continuity with the heritage of Landsat data must be optimized, a program is needed to introduce better technology and advanced capabilities. Examples are elevation and other data from radar and enhanced discrimination of land features from hyperspectral sensing and other technologies. The aerospace industry can provide enhanced capabilities for Earth observing with sensor webs and adaptive sensing strategies.

An application area for land imaging that has not yet been mentioned, Mr. Birk said, is climate monitoring. The Global Climate Observing System Group has defined 26 atmospheric, oceanic, and terrestrial variables that are central to climate monitoring. The U.S. has committed to providing a monitoring capability for these terrestrial variables, and a consistent, long-term operational program is needed to fulfill that commitment.

Panel Responses to Questions

At the close of the panel presentations, Gen. Dickman asked the panelists to comment on how they would make the design trades implied by the diversity of potential users and user interests in an environment of constrained resources. Mr. Good suggested that decisions be made on the basis of services or capability that industry is willing to provide at a fixed cost. Higher resolution imagery and new sensing modalities such as hyperspectral sensing can now be priced for operational systems.

Gen. Dickman rephrased his question in terms of how competing capabilities, such as resolution and swath width, should be weighed. Mr. LeRoy said that such decisions will have to trade combinations of competing capabilities against cost. For example, additional instruments on one spacecraft could provide both higher resolution and broad swath coverage. Ron Birk described how multivariate analyses might be applied to assess trades among community needs. Tools such as operational system simulator experiments can be used to vary system parameters and evaluate the resulting performance. Simulations of this kind might be employed as part of a user community meeting to show the impact of different design parameters on system capability. Mr. LeRoy added that iteration of design options with the user community will be needed to arrive at an optimal solution, and sufficient time has to be provided to conduct that iterative process. Dr. Kalluri agreed that the issue will come down to trading cost against capability.

As a final question to the panel, Gen. Dickman asked how important a single lead point of contact in the Federal government would be to the industry. The panelists agreed that the program becomes much more workable when their industry can work with a single Federal point of contact. Gen. Dickman added that a single lead agency will need to work closely with an industry partner that has experience with building and managing spacecraft systems, particularly if the lead agency is not primarily in the business of developing and operating space-based systems.

Open Discussion and Response to the Working Group's Preliminary Findings

Dr. Whitney moderated the open discussion and response session that concluded the workshop. He reminded the audience of Gen. Dickman's point that the hard work of implementing a long-term, operational program for land imaging will just be starting when the FLI-IWG strategy is released in February 2007. If LDCM is launched on its current schedule in 2010 or 2011, then a successor mission will be needed in the 2015–2016 time frame. Even for the near term, naming a new agency home for Landsat, if that happens, will not mean that the program has a budget; it will only provide a mechanism for the program to get into the Federal budgetary process. He asked for the community's support in building a compelling case for future moderate resolution land imaging capability. In opening the floor to comment, he asked the participants to focus on the following questions:

- What are the future societal benefits of moderate resolution imagery?
- What is your vision of the future of moderate resolution imagery?
  - Who provides it?
  - What are the data policies?
  - What are the technologies?
- If you could implement your vision for the future of moderate resolution land imagery, what would be the best combination of governance, technology, and policy for that vision?
- What should be different in the future, and what would be the benefits of the change?

Comment 1: A member of the academic community involved with training the next generation of Landsat users commented that part of managing for land imagery of the future is educating the user community. She had not heard much about education at the workshop and wanted to encourage the FLI-IWG to include the academic teaching community in the future.

Comment 2: Professor Joanne Gabrynowicz, cochair of the USGS's Archive Advisory Committee and Director of the National Remote Sensing and Space Law Center at the University of Mississippi, read a statement from the Archive Advisory Committee, a number of whose other members were also present for the workshop. The statement reiterates recommendations that the committee has made previously to the Secretary of the Department of the Interior. (*Statement below was transcribed from recording and may contain errors due to audibility.*)

> **Recommendation:** That the Department of the Interior should be the single governing FLI [Future Land Imaging] body. DOI should also establish an independent external entity reporting to the Secretary to represent the interests of the user community. Regarding the operational scope of FLI, the FLI program must go beyond supplying data to providing relevant information to address economic, environmental, and other societal needs, irrespective of system architecture or ownership of assets. The program must track performance metrics to report value to society.

In her individual capacity as a long-time observer of the remote sensing community, Prof. Gabrynowicz said it is imperative that the data be available at no cost. If the data are not available at no cost, then the program will be attempting to recover cost of satellites and operation, which is something neither the public nor private sector has been able to do successfully. For remote sensing to achieve its potential, the same approach must be taken to land remote sensing satellites as has been taken with weather satellites and the Global Positioning System (GPS) by providing the data at no cost.

Comment 3: An audience member from SAIC commented that he thought the societal benefits of Landsat-type moderate resolution land imaging were already defined in the *Strategic Plan for the U.S. Integrated Earth Observation System.*[1] He also understood that the necessity of continuing Landsat had been established at a September 2004 White House conference in which multiple agencies made their arguments for that necessity, and a decision was made then to continue it, albeit on a platform that turned out to not be viable. He also understood that the December 2005 memorandum from the Director of OSTP had charged the FLI-IWG with developing a plan, not a strategy. A plan, he said, should contain much more specifics than a strategy and is the goal that needs to be reached. Any plan without funding is unexecutable, so a viable plan would scope out the costs and the partnership funding shares. The capabilities of the system will fundamentally determine what other organizations, whether they be other nations or other industry partners, seek to emerge as willing partners in this effort. If the data quality or revisit frequency fail to satisfy the requirements and needs, and costs are not recoverable, then there will be no industrial partners.

It appears, this commenter continued, that in this day and age it is possible for a commercial company, albeit government-backed, to recover its costs on a moderate resolution, broad area coverage system. He said that, based on the latest annual revenues of SPOT, a satellite designed with a 7-year operational life can make $70-80 million per year and is therefore on a cost recovery path—something deemed unachievable before. A plan to achieve all the requirements and needs of the operational agencies must assess what their requirements and needs are. This commenter does not see that the FLI-IWG has, up to this point, culled the agencies for their yearly requirements with respect to resolution, revisit frequency, and area coverage. If that were done, the commenter believes the resulting picture would distill a center of gravity for the type of system that would be most useful and satisfy the greatest quantify of needs per taxpayer dollar. A higher resolution system, he said, is inherently capable of meeting lower-resolution requirements. Yet a 30 m system cannot satisfy any requirements for spatial resolutions below 30 m. So a higher-resolution system is inherently capable of meeting more agency needs.

Comment 4: This participant from the Department of Geography, University of Maryland, said that what he had heard so far at the workshop has been a reflection of the past. Although there was some innovative thinking from the applications panel about the future, he did not hear any innovative, forward thinking from the aerospace industry panel. If the future land imaging program being discussed is at least 10 years away, there will be huge leaps in technology in that time. The discussion is missing forward-looking thinking about what might be possible.

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[1] This strategic plan was released in April 2005 by the Interagency Working Group on Earth Observations, which works under the NSTC Committee on Environment and Natural Resources.

Exhibit 8

In response to several of the comments, Dr. Whitney asked any participants who had access to analyses or vision documents that the FLI-IWG may not have seen to send them to the Working Group. Analyses of projected needs would be particularly valuable.

Comment 5: A workshop participant from NASA Goddard Space Flight Center advocated consideration of a schedule for launching a FLI asset before 2015. Reasons given were the need for higher resolution imagery before 2015 and the possibility that the LDCM launch might not be successful.

Comment 6: The FLI-IWG should be looking at moderate resolution imaging more broadly than just land imaging—for example, moderate resolution sea surface temperature monitoring, coastal process monitoring, sea ice monitoring, and atmospheric processes, including cloud imaging. From a Landsat perspective, scenes are always ordered as cloud-free land images. A second comment was to encourage the FLI-IWG to keep the public informed about what it is doing.

Comment 7: Kass Green asked what the user community needs to do to show support for implementation and not just planning, given that several years have passed while LDCM implementation has been stalled. Even the current procurement is still encountering controversy. What more could be done to get things unstuck and finally moving?

Dr. Whitney replied that the whole process being undertaken by the FLI-IWG is an attempt to answer that difficult question. A difficulty for Landsat has been that the user community is very dispersed and disparate; it is difficult to identify "heavy hitter" constituents that can take the case to Congress and the Office of Management and Budget. Something that could help would be a way to communicate the cumulative value of land imaging with something more than a long list of application anecdotes. Some way is needed to sum up, objectively and analytically, both the aggregate societal benefits from moderate resolution imagery and the opportunity costs of the currently unmet needs.

Comment 8: Susan Carson Lambert read some of the comments she received from users in State and local government that distilled a vision of what is needed in 10 years. For example, "satellite imagery should be as ubiquitous as NOAA weather data on the weather.com website" and "you should [be able to] just ask a question and get an answer with the processing happening [in the background]." Other comments addressed future availability of land change analyses, desired resolution in land imagery, and the necessity for political support at the State and Federal levels to ensure program continuity.

Comment 9: It is not a disadvantage that there are 200 uses for moderate resolution land imagery, this commenter said. A variety of uses in a diverse society should be a strength in making the case for the program to budget decision makers. The first and most important step is that a single agency needs to be in charge of the program. That entity needs to be the salesperson for the program.

Comment 10: As a reply to some of the preceding comments about the lack of innovative thinking from industry, Mr. LeRoy said that industry's job is to respond to what customers want. If that dialogue with customers happens, industry can come up with a system to do it. But time to implement it will be necessary.

Comment 11: The background message that this commenter seemed to hear was that a single satellite would be in the $300–$600 million range. He said that the era for that kind of thinking is past. If some time were spent talking about what was needed, it would roll out quickly, and the solution would not require a satellite costing $300-$600 million. The dialogue has been started, he concluded, and now we need to keep up the momentum.

Comment 12: Foreign and civil competitors will spur us to action, this commenter said. When [a new alternative system] is on orbit next June, with 4.5 times better resolution in the visible and infrared bands, with twice the swath width of Landsat at one-fifth the cost of building and launching Landsat 7, we will be forced to deal with a world in which lower cost, broad area imagery will be available. Other emerging developments include the Chinese space agency brief at the National Space Symposium at the Center for Strategic and International Studies on a four optical, four SAR system that will be launched imminently. The small satellite approach is affordable and does not require charging high costs for products. The future of spectral-mode sensing, he continued, is hyperspectral, not multispectral. Other countries are looking for teaming partners to put up a hyperspectral system with better resolution than Landsat before LDCM is launched. So the question, the commenter continued, is whether the United States will become an "also ran" in spectral-mode sensing. Hopefully not, if national policy is carried out. We have the technology, the money, the requirements and the needs, we have Joint Staff-endorsed hyperspectral architectures. We have U.S. Government strategic plans. We have everything we need to act, but we don't.

Comment 13: Ron Birk commented that the new technical thing introduced today was [his suggestion for] an interactive dialogue with a system simulator to arrive at a community consensus. He pointed to the divergent opinions expressed in the preceding comments as an indicator of the need for some way to drive to a consensus on what a future system should do.

Comment 14: In this week's *Space News*, the Director of the Brazilian National Institute for Space Research stated in an interview, "Some American officials do not realize how important Landsat has been to the world community and how much good will the U.S. could generate by having a free and open data policy. This is really grossly underestimated in many U.S. circles. The point that I have been making here over and over is that there is so much that the U.S. could gain, both internally and externally, from an open data policy, that it doesn't make any sense to adopt any other policy."

Dr. Whitney reminded participants that the FLI-IWG website, www.landimaging.gov, has the email address for sending additional comments to the Working Group (survey@landimaging.gov) and a link to the ASPRS survey. He thanked the panelists and the audience for participating in the workshop. The workshop was adjourned at 5:03 p.m.

The presentations made by Dr. Whitney and panelists can be found at the FLI-IWG website, www.landimaging.gov.

Exhibit 9

"American Society of Photogrammetry and Remote Sensing Survey on the Future of Land Imaging," Reprint from *Photogrammetric Engineering & Remote Sensing,* January 2007

Report to the White House Office of Science and Technology Policy Future Land Imaging Working Group

on the

American Society for Photogrammetry and Remote Sensing Survey on the Future of Land Imaging

by Kass Green, Jim Plasker, Gerald Nelson, and Don Lauer

I. Overview of the Survey

The Landsat program has been the most successful satellite remote sensing program dedicated to civilian land remote sensing observations. Born of civilian rather than military needs, the Landsat family of satellites has provided humanity with 34 years of standardized, moderate spatial resolution, multispectral images of the world. No other data set allows us to assess the human condition so effectively over such a long period of time. As stated by Dr. John Marburger, director of the White House Office of Science and Technology Policy (OSTP), "Landsat is a national asset, and its data have made – continue to make – important contributions to U.S. economic, environmental, and national security interests" (Marburger, 2004).

Currently there are two Landsat satellites collecting moderate resolution imagery of the Earth - Landsats 5 and 7. Launched in 1984, Landsat 5 has far outlived its expected operational life. While it still collects data, the system lost its ability to download data outside of ground station communication cones over 10 years ago and its future operations will be severely limited by its quickly depleting fuel supply. Landsat 7 was launched in 1999 and operated flawlessly for almost 4 years. Unfortunately, in May 2003, the Landsat 7 sensor (called ETM+) experienced a partial but permanent failure of its scan line corrector resulting in the effective loss of approximately 25% of the data in each scene. Because of this, the world is currently experiencing a partial gap in the collection of Landsat data. Data collected by Landsat 5 are not available for critical portions of the world, including parts of Russia and Africa. Data collected by Landsat 7, while worldwide, are insufficient for many applications, especially those requiring change detection over short time spans.

Understanding the urgency and the growing gap in Landsat coverage, the White House Office of Science and Technology Policy issued a memo in December 2005 calling for NASA to build and launch a Landsat follow on mission which will be operated by USGS. Significantly, the OSTP memo also dictated that "…the National Science and Technology Council, in coordination with NASA, DOI/USGS, and other agencies and EOP offices as appropriate, will lead an effort to develop a long-term plan to achieve technical, financial, and managerial stability for operational land imaging,…" In other words, the White House directed the agencies to determine how to migrate moderate resolution earth remote sensing from a satellite by satellite approach into a long term operational program. The result was the formulation of the Future of Land Imaging Inter-agency Working Group (FLI-IWG) whose responsibilities are comprehensive and include conducting a fact-finding and needs assessment to answer the question, "Why does the U.S. need moderate-resolution land images?" (FLI-IGW, 2006).

To provide quantitative data to respond to this question, the American Society for Photogrammetry and Remote Sensing (ASPRS) conducted a survey of the geospatial user and provider communities for the purpose of estimating the benefits of moderate resolution imagery. Moderate resolution imagery was defined as imagery with spatial resolution between 5 and 120 meters. The goals of the survey were to:

- estimate the societal benefits of U.S. moderate resolution data,
- better understand current operational and research uses of moderate resolution data, and
- identify user requirements in moderate resolution technology and data policy.

The survey questions (available on line at www.asprs.org/) were created and reviewed by this paper's authors with input from members of the FLI-IWG.

The survey was initiated on July 5, 2006 and email blasts requesting response were sent out to members of ASPRS, the Management Association of Private Photogrammetric Surveyors (MAPPS), the Urban and Regional Systems Association (URISA), the National States Geographic Council (NSGIC), the American Congress on Surveying and Mapping (ACSM), an extensive customer list maintained by the USGS Earth Resources Observation and Science (EROS) Center, the International Society for Photogrammetry and Remote Sensing (ISPRS), and numerous other organizations. The survey closed on Sept. 9, 2006. Over the short two months that the survey was open, ASPRS received 1,295 responses from users and producers of geospatial data and information around the world.

This report presents the results of the survey and is organized as follows:

- Section II describes the characteristics of the survey respondents.
- Section III summarizes respondents' opinions concerning the technical and institutional attributes of moderate resolution satellite imagery.

continued on page 6

Exhibit 9

continued from page 5

- Section IV presents estimations of the economic value of moderate resolution imagery.
- Section V summarizes respondent opinions concerning the impact of not having moderate resolution satellite imagery available in the future.
- Section VI presents respondents' opinions concerning moderate resolution data policy.
- Section VII summarizes the report and present conclusions.

II. Description of the Respondents

Survey participants represent all sectors of the geospatial profession with similar participation from the academic, commercial and government sectors as shown in Figure 1. The majority of participants (71%) use Landsat data as their primary source of moderate resolution data, and 72% state that Landsat is a ***primary*, *critical data set*** for their applications.

While the respondents work in all sectors, they use moderate resolution imagery primarily to serve government or other non commercial clients with 82% of their moderate resolution imagery work performed for the academic, non-profit, or government sectors. Fully 50% of their work is performed directly for the government sector alone (see Figure 2).

Respondents use moderate resolution imagery in a wide variety of activities. As Figure 3 demonstrates, the diversity is impressive with the largest sector (environmental) representing only 20% of the respondents. Figure 3 further divides the Environmental sector into the FLI classes of coastal zone management, emergency/disaster management, land use planning and management, water resource management, and ecological forecasting.After environmental, the next most significant activities performed by the respondents are general mapping (17%), agriculture (11%), and forestry (11%).

Moderate resolution imagery is used in local, state/provincial, regional, national, continental and global projects. The highest proportion of use (38%) is in regional projects (see Figure 4).

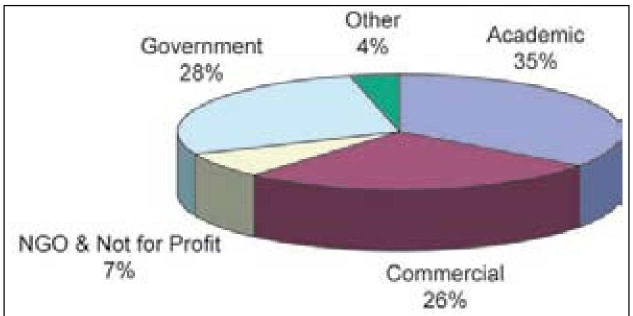

Figure 1. Respondents by sector.

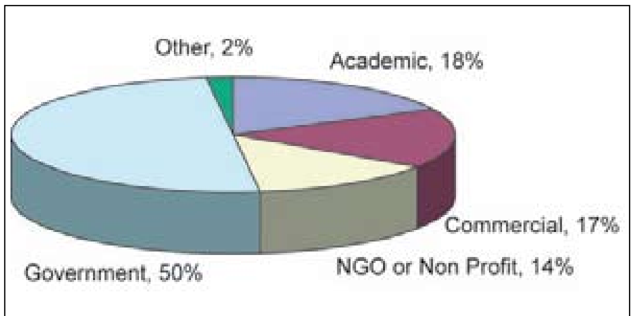

Figure 2. Sectors served by respondents.

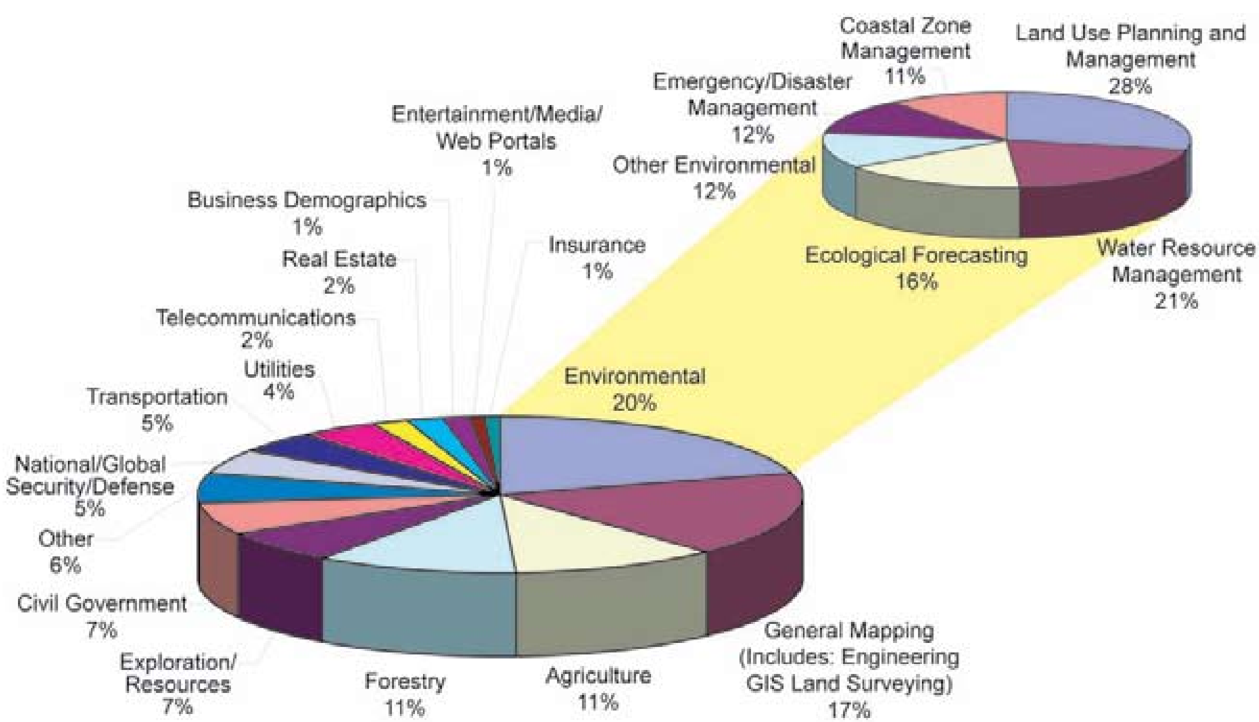

Figure 3. Types of activities for which moderate resolution imagery is employed.

Many of the programs using moderate resolution data were established decades before the first Landsat launch and have incorporated Landsat and moderate resolution imagery as the imagery became accessible. However, as Figure 5 shows, 44 percent of the operational programs started within the last 9 years, which coincides with the 1999 launch of Landsat 7 and the increased accessibility of the imagery and dramatic reduction of prices resulting from the Land Remote Sensing Policy Act of 1992 (15USC-Chapter 82).

While moderate resolution imagery supports both academic and operational programs, 47% of the participants work in either a purely operational program or a combined operational/research program. The variety and creativity of the operational programs is remarkable, ranging from support of Department of Defense programs and water rights monitoring, to wildlife re-introduction and crop estimation. Table 1 lists a small subset of the purposes of respondents' operational programs.

III. Opinions Concerning the Technical and Institutional Attributes of Moderate Resolution Satellite Imagery

While 71% of the respondents rely on Landsat as their primary moderate resolution data source, 78% of the respondents with an opinion about Landsat stated that current Landsat 5 and 7 data ***do not*** meet all of their needs given the current scan line corrector problems of Landsat 7 and coverage limitations of Landsat 5. Approximately 79% of the same respondents stated that if the scan line corrector failure on Landsat 7 had not occurred, Landsat 7 data ***would*** meet their current needs.

The top 5 reasons why participants use Landsat data rather than other remote sensing data are (in order of importance)

1. Landsat data are more accessible
2. There is a large Landsat archive containing over 30 years of consistent data
3. Landsat data is relatively less expensive
4. The extent of Landsat scenes is more appropriate for the respondent's project
5. Landsat has more repetitive coverage

Conversely, barriers to using other types of moderate resolution data include

1. Cost barriers
2. Insufficient historic data available
3. Lack of repetitive coverage
4. Lack of coverage over area(s) of interest
5. Lack of spectral band(s)

Table 2 lists the respondents' five highest priority attributes of moderate resolution imagery. A consistent thread throughout the respondents' answers is

- the importance of cost to their decisions of what type of imagery to use,
- the importance of spectral and spatial resolution to their decisions of what type of imagery to use, and
- the high value placed on the existence of repetitive coverage and an archive of historical data.

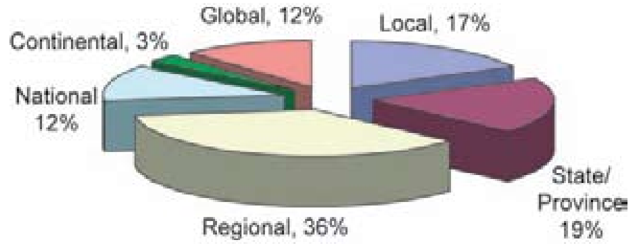

Figure 4. Geographic scope of moderate resolution projects.

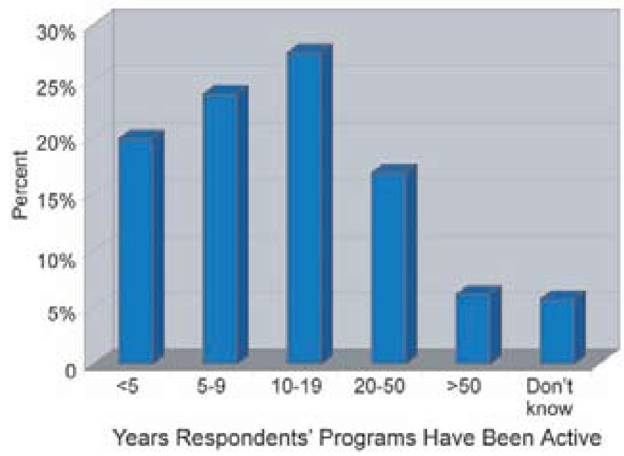

Figure 5. Age of Operational Programs.

Table 1. Examples of operational uses of moderate resolution imagery.

Support of DoD operations	Wildland fire risk assessment
Emergency response	Recreation planning
Inventory of toxic releases	Soil analysis
Coastal change analysis	Ecosystem mapping
Mineral exploration	Water resource planning and administration
Water rights monitoring	Snow and ice monitoring
Land use and land cover change	Detecting and monitoring volcanic activity
Crop estimates	Deforestation monitoring
Forest management	Wetlands rehabilitation
Space cartography	Weather prediction
Wildlife reintroduction	Irrigation management
Design of defense systems	Carbon cycle monitoring
Range management	Mapping groundwater discharge zones
Invasive species monitoring	
Monitoring grant performance	

Table 2. Five highest priority attributes of moderate resolution imagery data (1 is highest).

Landsat Data	Other Moderate Resolution Data
1. Relatively low cost	1. Relatively low cost
2. SWIR bands	2. SWIR bands
3. Existence of archive	3. Spatial resolution
4. Thermal band (6)	4. Existence of archive
5. Spatial resolution	5. Thermal band(s)

continued on page 8

Exhibit 9

continued from page 7

Respondents believe that the top five ways to increase the utility of moderate resolution imagery are (in order of importance)

1. Lower cost data
2. More frequent temporal coverage
3. Greater spatial resolution
4. More spectral resolution
5. Easier access to data

Figures 6 and 7 display respondents' opinions concerning desired spatial and temporal resolution of future moderate resolution systems.

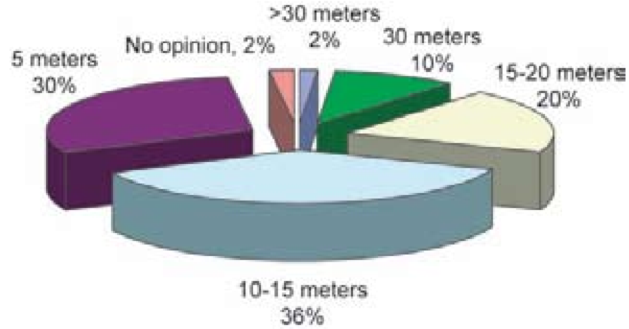

Figure 6. Desired spatial resolution of future moderate resolution systems.

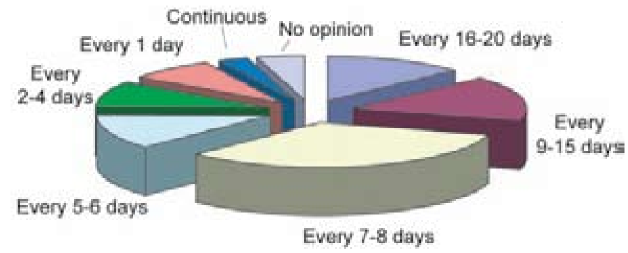

Figure 7. Desired revisit frequency of future moderate resolution systems.

IV. Respondent Opinions Concerning the Economic Value of Moderate Resolution Imagery

Thirty eight percent of the users of moderate resolution imagery believe it would not be possible to provide the same level of service to their clients if Landsat or other moderate resolution imagery were not available. The remaining respondents estimate the economic impact to their clients if moderate resolution data were not available to be ***$1.278 billion per year***. Of that, the value attributable to the loss of Landsat imagery alone is estimated to be ***$935.8 million per year***.

As illustrated by Figure 8, in the absence of Landsat, users are most inclined to turn to foreign sources of moderate resolution imagery (primarily the French SPOT, Japanese Aster, and Indian IRS systems).

Table 3 lists the economic activities which will bear the impact of a loss of moderate resolution imagery.

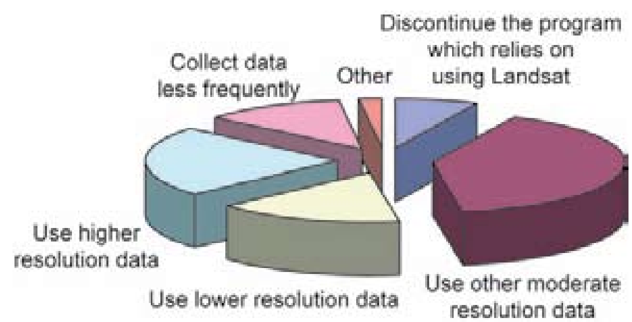

Figure 8. Alternatives if Landsat data is unavailable.

V. Respondent Opinions Concerning Moderate Resolution Data Policy

Finally, respondents were asked to rate their level of agreement with several statements on moderate resolution data policy. Figure 9 lists the opinions in order of respondents' agreement with them. Strikingly, the two most strongly agreed with opinions are that "Landsat and future moderate resolution land imaging data are a national asset and should become a sustained operational program of the U.S. Government," and that "The U.S. Government should distribute Landsat and future moderate resolution land imaging data at little or no cost."

Table 3. Activities impacted by a loss of moderate resolution data listed in order of loss with 1 being the highest loss and 8 being the lowest loss.

Loss of Landsat	Loss of Other Moderate Resolution Imagery
1. Land Use Planning and Management	1. National/Homeland Security Management
2. Agriculture and Forestry	2. Emergency/Disaster Management
3. Water Resource Management	3. Land Use Planning and Management
4. Ecological Forecasting	4. Water Resource Management
5. National/Homeland Security	5. Agriculture and Forestry
6. Emergency/Disaster Management	6. Ecological Forecasting
7. Coastal Zone Management	7. Coastal Zone Management
8. Transportation Management and Infrastructure Planning	8. Transportation Management and Infrastructure Planning

VII. Summary and Conclusions

ASPRS is extremely thankful to its members and other geospatial professionals who took the time from their busy schedules to complete the Future of Land Imaging survey. There is still considerable information that has not yet been mined from the responses and we will continue to analyze the results over the next 6 months.

The importance of moderate resolution data is perhaps best stated in the respondents' words and on the numerous web sites showcasing the operational uses of moderate resolution imagery. We received hundreds of eloquent, persuasive and powerful testimonials to the value of moderate resolution imagery.

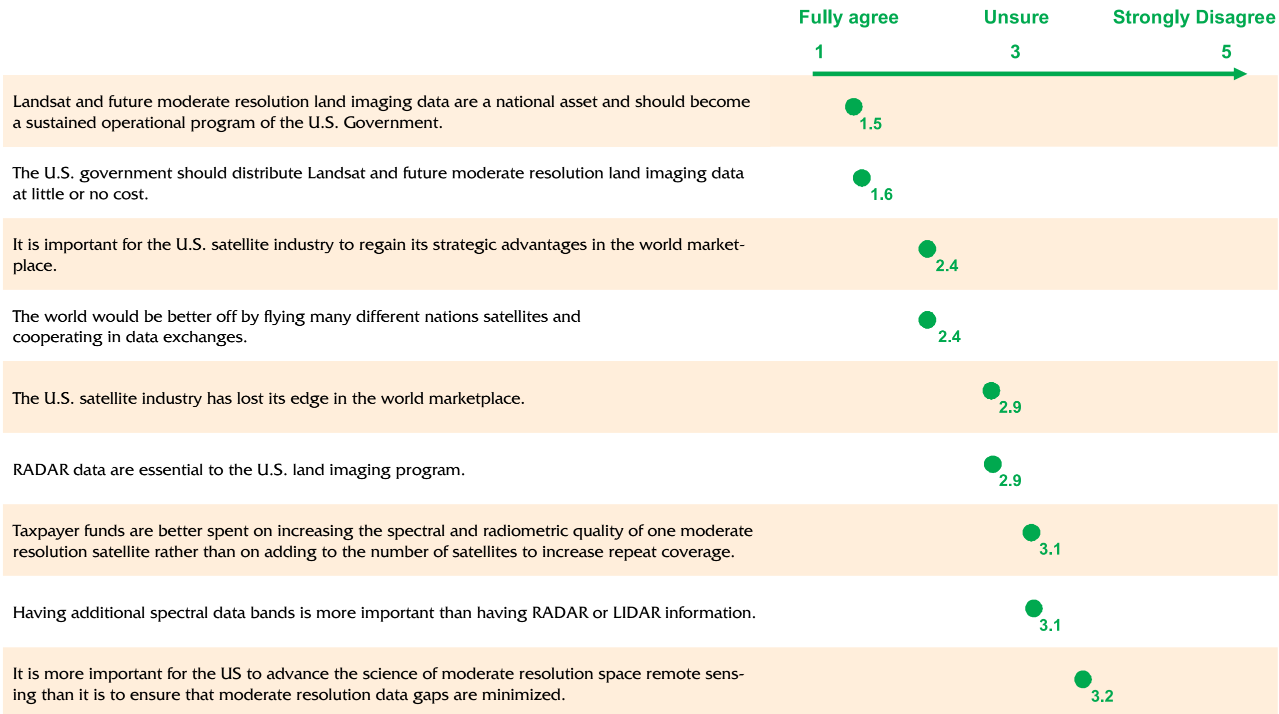

Figure 9. Respondents' opinions on data policy.

Over the last 30 years, the political support for moderate resolution imagery has suffered from its biggest strength – its broad base of users who tend to focus on the very diverse problems of the globe rather than organizing to support the underlying satellite program.

This survey and the FLI have been instrumental in developing a focused constituency passionately committed to the future of a Landsat-like program.

The survey has shown us that

- The operational uses of moderate resolution data are global, extremely diverse, and rich in creativity and impact.
- Discontinuation of a U.S. managed moderate resolution program would cost society and humanity almost $1 billion per year in beneficial activity.
- While users of moderate resolution data come from all sectors, they serve primarily public agencies and non profit organizations.

To expend our resources on global issues, we must know that the information is ***timely***, ***objective***, ***reliable***, and ***consistent***.

- •; Can our food security rely on information gathered by our biggest agricultural competitors?
- Can our homeland security and defense depend on other governments monitoring economic and environmental change world wide?
- Can our disaster response rely on the availability and timeliness of satellites controlled by other governments?
- Can we afford to put so much of our resources and security in the hands of other countries?
- Do we want to surrender leadership in moderate resolution remote sensing to the rest of the world?

The American public and the global community need moderate resolution multi-spectral land remote imagery for

- Environmental security
- Homeland security
- Economic security
- Food security

It is a public need, and must be provided as a public asset.

Work Cited

Marburger, J. 2005. *Landsat Data Continuity Strategy Adjustment*. Executive Office of the President. Office of Science and Technology Policy. December 23, 2005.

Future of Land Imaging Interagency Working Group. 2006. U.S. Land Imaging Needs & Long-Term Continuity. PowerPoint presentation at the ASPRS national convention on May 3, 2006. Reno, Nevada.

Public Law 102-555. 1992. 1992 Land Remote Sensing Policy Act.

Exhibit 9

Exhibit 10
About the National Science and Technology Council, the Committee on Environment and Natural Resources, and the Interagency Working Group on Earth Observations

The National Science and Technology Council (NSTC), a cabinet-level council, is the principal means for the President to coordinate science and technology policies across the Federal Government. NSTC acts as a virtual agency for science and technology to coordinate the diverse parts of the Federal research and development enterprise. An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from information technologies and health research to improving transportation systems and strengthening fundamental research. This council prepares research and development strategies that are coordinated across Federal agencies to form an investment package aimed at accomplishing multiple national goals. To obtain additional information regarding the NSTC, contact the NSTC Executive Secretariat at (202) 456-6101.

About the Committee on Environment and Natural Resources (CENR)

The purpose of the Committee on Environment and Natural Resources (CENR) is to advise and assist the NSTC to increase the overall effectiveness and productivity of Federal research and development efforts in the area of the environment and natural resources. This includes maintaining and improving the science and technology base for environmental and natural resource issues, developing a balanced and comprehensive research and development program, establishing a structure to improve the way the Federal Government plans and coordinates environmental and natural resource research and development in both a national and international context, and developing environment and natural resources research and development budget crosscuts and priorities.

Co-Chairs:

Sharon Hays, Office of Science and Technology Policy
Conrad Lautenbacher, National Oceanic and Atmospheric Administration
George Gray, Environmental Protection Agency

Executive Secretary: Carla Sullivan carla.sullivan@noaa.gov

Organizational Members:
Department of Agriculture
Department of Commerce
Department of Defense
Department of Energy
Department of Health and Human Services
Department of Homeland Security
Department of the Interior
Department of Justice
Department of State
Department of Transportation
Environmental Protection Agency
National Science Foundation
National Aeronautics and Space Administration
Smithsonian Institution
Federal Emergency Management Agency

Also represented on the CENR:

Office of Science and Technology Policy
Office of Management and Budget
National Economic Council
Council of Economic Advisors
Domestic Policy Council
Council on Environmental Quality

Cooperating departments and agencies include:

Department of Housing and Urban Development, Tennessee Valley Authority; and other Executive organizations, departments and agencies as the co-chairs may designate.

The Interagency Working Group on Earth Observations

The Interagency Working Group on Earth Observations was chartered by the CENR for the purpose of developing the Strategic Plan for the U.S. Integrated Earth Observation System, and to provide U.S. contributions to the Global Earth Observation System of Systems (GEOSS). The Interagency Working Group's charter expired in December, 2004, and the working group has been replaced with a standing subcommittee under CENR, the United States Group on Earth Observations (US GEO). To obtain additional information regarding the US GEO, contact the US GEO Executive Secretariat at (202) 482-5921.

Future of Land Imaging Interagency Working Group
Members

Jeffrey S. Amthor
Department of Energy

Craig Baker
Department of Defense

Glenn R. Bethel
Department of Agriculture

Barron R. Bradford
Department of the Interior

Raymond A. Byrnes
Department of the Interior

John W. Cullen
Department of the Interior

Bradley D. Doorn
Department of Agriculture

Eve Douglas
Department of Commerce

Fernando R. Echavarria
Department of State

Jay W. Feuquay (deceased)
Department of the Interior

Edward C. Grigsby
National Aeronautics and Space Administration

Michael Hales
National Geospatial-Intelligence Agency

Theodore F. Hammer
National Aeronautics and Space Administration

James D. Hipple
Department of Agriculture

Riley D. Jay
Department of Defense

Douglas P. McGovern
Department of Defense

Rick Mueller
Department of Agriculture

Bruce K. Quirk
Department of the Interior

Colonel Patrick H. Rayermann
Department of Defense

D. Brent Smith
Department of Commerce

Kuppusamy Thirumalai
Department of Transportation

Gene Whitney
Office of Science and Technology Policy

Charles Wooldridge
Department of Commerce

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NATIONAL SCIENCE AND TECHNOLOGY COUNCIL