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National Land Imaging Requirements (NLIR) Pilot Project Summary Report—Summary of Moderate Resolution Imaging User Requirements

By Carolyn Vadnais and Greg Stensaas

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National Land Imaging Requirements (NLIR) Pilot Project Summary Report—Summary of Moderate Resolution Imaging User Requirements Manuscript

By Carolyn Vadnais[1] and Greg Stensaas[2]

Introduction

As part of the National Land Imaging Requirements (NLIR) Project, the U.S. Geological Survey (USGS) will develop and operate a functional capability to obtain, characterize, manage, maintain and prioritize all Earth observation (EO) land remote sensing user requirements. The goal is a better understanding of community needs that can be supported with land remote sensing resources, and a means to match needs with appropriate solutions in an effective and efficient way. The NLIR Project will enable program managers to systematically manage, assess, and exploit EO user requirements to support data-driven decisions to better serve the user community.

The NLIR Project comprises two components. The first component is focused on the development of a system to capture, store, and analyze user requirements. The system, called the Earth Observation Requirements Evaluation System (EORES), is being developed jointly with the National Oceanic and Atmospheric Administration (NOAA) through a process that will incrementally deliver the full capability in the next 12–18 months. The second component is the mechanism and processes to elicit and document user requirements that will populate EORES.

To develop the second component, the user requirements elicitation methodology was exercised and refined through a pilot project that ran from June through September 2013. The pilot project served as a risk reduction activity for the NLIR Project and builds on the best elements of several well-documented methodologies and previous work by NOAA and the U.S. Group on Earth Observations (USGEO) as described in the National Strategy for Civil Earth Observations (Office of Science and Technology Policy, 2013). This pilot project focused specifically on requirements for moderate resolution imagery [5–120-meter (m) resolution]; however, the overall NLIR Project elicitation will follow a solution-agnostic approach and address all land EO user requirements to establish a baseline expected to endure for multiple years.

The purpose of this summary report is to provide a high-level overview of the requirements elicitation process that was exercised through the pilot project and provide an early analysis of the sample of moderate resolution imaging user requirements developed to date to support ongoing USGS sustainable land imaging study needs. The elicitation process documented in this report and lessons learned in the pilot project will be used to enhance and fully document the NLIR elicitation process.

The pilot project engaged a limited set of Federal Government users from the operational and research communities, and therefore, the information collected represents only a subset of all land imaging user requirements. However, based on a comparison of results, trends, and analysis, the pilot

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project results depicted a strong baseline of typical applications areas and user needs for moderate resolution imagery.

Because these results are preliminary and represent only a sample of users and application areas, the information from this report should only be used to indicate general user needs for the applications covered. Users of the information are cautioned that use of specific numeric results may be inappropriate without additional research. Any information used or cited from this report should specifically be cited as preliminary findings.

Background

Through the NLIR Project within the Land Remote Sensing Program, the USGS is developing a functional capability to obtain, characterize, manage, maintain, and prioritize land remote sensing requirements with the goal of better understanding the community needs that can be supported by land remote sensing resources and to match needs with appropriate solutions in an effective and efficient way. This capability will help guide program development and direction and support program and budget justifications. The current (2013) NLIR Project comprises two primary components: (1) development of a requirements and capabilities information repository and the analytical tools to compare requirements and capabilities; and (2) the pilot project that is the subject of this summary report.

Report Overview

The "Methodology" section describes, at a high level, the methodology used to generate the representative sample of user requirements and the "Results and Analysis" section describes the preliminary results and accompanying analysis. The final section draws conclusions from the results and the analysis to date and identifies the next steps in the process. Appendix 1 contains a list of abbreviations used in the report.

Important Limitations

The overarching purpose of the pilot project was to develop an effective, transparent, and repeatable process to capture land imaging user requirements. As would be expected in a pilot effort, a starting methodology was developed, then tested, then modified, and tested again, and the project team will continue to make additional refinements in the process before the final documentation is delivered. Because of the pilot project focus on moderate resolution applications and requirements only, and because of the limited time available, the team was not able to exercise all elements of the process, specifically some later elements of the process that would follow extensive work with Subject Matter Experts (SMEs) to refine and solidify the full set of user requirements, such as prioritizing requirements and assigning relative weights. Additional work will be completed between the end of pilot project data collection (September 2013) and the closeout of the project in January 2014 to ensure that a comprehensive process is developed and delivered.

Similarly, the pilot project did not elicit requirements from the full spectrum of users and potential users, nor did the pilot project formally validate the requirements developed. Because the set of user requirements described and analyzed in this report is the result of an evolving process and selective elicitations, it should not be considered a comprehensive or definitive statement of moderate resolution imaging requirements.

Methodology

The pilot project served as a risk reduction activity for the overall NLIR Project by developing and exercising processes for the elicitation and documentation of user requirements in a platform agnostic format that ensures requirements are captured, evaluated, and prioritized in a traceable, transparent and repeatable manner. Focusing the pilot project on moderate resolution imaging bounded the project scope and led to the generation of a set of preliminary user requirements that may be informative for the USGS in the near term. This report conveys a description and analysis of these moderate resolution imaging requirements while the project team finalizes and documents the requirements elicitation process.

The pilot project used a two-part strategy to meet its objectives: (1) the main effort developed and used a formal requirements elicitation process; and (2) a secondary effort completed an informal survey of state geospatial liaisons. The remainder of the Methodology section provides an overview of these two activities.

Scope

The pilot project focused on applications for moderate resolution imagery within the U.S. Department of Agriculture (USDA) and the Department of the Interior (DOI), and considerable effort was expended to try to ensure a wide sample of application areas across the two Departments.

Within USDA, the team engaged the USDA Remote Sensing Advisor and the U.S. Forest Service Remote Sensing Program Manager to identify the appropriate initial contacts within each of the subordinate Agencies and Services.

Within DOI, the approach was two-fold. First, the team contacted the DOI Remote Sensing Working Group member for each of the Bureaus (see table 1) to explain the project and seek their advice about potential application areas and SMEs. Second, the team contacted or met with nearly all of the 31 USGS Program Coordinators to gain an understanding of their activities and identify appropriate SMEs.

Table 1.   Member Bureaus of the Department of the Interior Remote Sensing Working Group (DOIRSWG).

Department of the Interior
Remote Sensing Working Group (DOIRSWG)

Member Bureaus

Bureau of Indian Affairs
Bureau of Land Management
Bureau of Ocean Energy Management
Bureau of Reclamation
U.S. Fish and Wildlife Service
National Park Service
Office of Surface Mining
U.S. Geological Survey

An important element of the pilot project was to engage practitioners within each application area rather than managers or headquarters personnel. Ideally the team was looking for individuals who work with moderate resolution data and develop or deliver the key products or services as part of their day-to-day job. These individuals are closest to the applications and generally have a clear

understanding of the value and any shortcomings associated with current (2013) data sources as it applies to their activity, as well as unmet needs at the user level.

The Requirements Elicitation Process

The elicitation process comprised two phases, both involving extensive contact with SMEs across the range of application areas examined. The first phase was the development of value trees to understand the current (2013) use and relative criticality of moderate resolution imagery to the application. The second phase was the capture of user requirements.

The following sections describe value tree development and data collection, followed by a description of requirements development and elicitation.

Value Tree Development and Elicitation

This step in the formal process includes three parts: (1) defining the structure and components of the value tree; (2) using expert elicitation to value the set of inputs to key products or services; and (3) identifying unmet needs.

Defining the Value Tree

The development of requirements begins with establishing the strategic context for the requirements. To establish this context, the project team reviewed the USDA and DOI strategic plans and the relevant strategic planning of subordinate organizations and activities. The team then developed value trees to identify the connections to departmental strategic goals and to collect information on current (2013) applications, the overall performance of those applications, and the performance of the inputs that go into them.

A value tree is a hierarchical framework in which top-level objectives may have other objectives or desired attributes within them, which may, in turn, have other lower-level attributes, and so on. A generic, single branch of the value tree using the DOI Strategic Plan to define the top of the tree is shown in figure 1. The DOI Strategic Plan identifies mission areas that have goals and specific strategies associated with the goals, forming the top part of the value tree. The project team, working in collaboration with SMEs from the bureaus and agencies, defined mission service areas that encompass similar activities aimed at achieving the strategy with which they are aligned. Then the elicitation team and the SMEs identified key products or services that represent the most important capabilities associated with each mission service area. Each of the key products or services are generated using some or all of a combination of direct observations from Earth observing systems (such as Landsat), other products or services, or models, collectively referred to as Earth observation datasets (EO datasets).

During the development of the value trees, when a branch with no connection to moderate resolution imaging was identified, the project team halted further development of that branch and focused on the branches with moderate resolution imaging application.

Figure 1.   Generic value tree for the U.S. Department of the Interior, showing the various levels connecting top-level mission areas to the observing systems that support them.

The top of the value tree may be defined in a number of ways depending on the intended application. For the pilot project, the team developed the value trees using an organizational construct that connects the delivery of value to top-level, organizational strategic goals and objectives. This may be contrasted with, and is compatible with the value tree construct based on Societal Benefit Areas such as those developed by the international Group on Earth Observations and USGEO. In this construct, the delivery of value is connected to a societal benefit rather than an organizational strategic goal. One advantage of the value tree development used in the pilot project is the ability to reorganize the key products or services under a different construct for the upper part of the value tree, minimizing additional work needed to support multiple applications.

After defining the structure of the value tree from the key products or services upward, the next step is to identify the EO dataset inputs into each key product or service and to determine the relative impact of each input on the production of the key product or service.

Determining Earth Observation Dataset Inputs and Their Impact

The project team used a combination of information from previous studies (Office of Science and Technology Policy, 2013, p 15-17; Miller and others, 2013) and review of agency plans, reports, and web sites, refined by extensive collaboration with SMEs, to determine the set of inputs into each key product or service. The team then entered the key products or services and their sets of inputs into a spreadsheet to be evaluated during the value tree elicitation sessions with the SMEs. Although the focus of the pilot project is on moderate resolution imaging requirements, all of the various inputs were identified and scored to provide a relative comparison for the moderate resolution imaging component.

As the elicitations continued, the team used higher levels of grouping of inputs to accelerate the value tree data collection. These variations were managed within the Portfolio Analysis Machine (PALMA™) model to ensure consistent analysis of the integrated results.

The Portfolio Analysis Machine (PALMA™) is a computer program developed by the MITRE Corporation (Schmidt, 2011) that enables the user to apply multi-attribute utility theory to the analysis of portfolios of systems as they relate to high-level goals. The PALMA™ software visually depicts the overall value tree, quantifies the qualitative information collected in the expert elicitation, and enables analysis of complex, multidimensional problems. The project team modeled the value trees in PALMA™ using the tree structure and scores elicited from the SMEs, then integrated the individual results into the larger, overall value tree for each Department.

The spreadsheet is structured to facilitate an orderly evaluation of each key product or service and its inputs using the swing weighting technique that was used in the development of the National Strategy for Civil Earth Observations (Office of Science and Technology Policy, 2013, p 15-17; Miller and others, 2013), and in similar ongoing work by NOAA (V. Ries and M. Yapur, National Oceanic and Atmospheric Administration (NOAA), oral communication, 2013). To standardize and calibrate the evaluation across the suite of different key products or services, the performance/satisfaction scale shown in Figure 2 was used throughout the elicitations.

Swing weighting is a proven technique to evaluate the relative criticality among many inputs when objective techniques are impractical or impossible (Kirkwood, 1997; Parnell and others, 2011, p. 334-337; Meyer and Booker, 2001, p. 3; Environmental Protection Agency, 2011, p. 1). It is a structured method of expert elicitation to define the impact of a particular capability (system, product, or service) on a key product or service. Subject matter experts assign an overall performance score (on a standardized scale, see Figure 2) to the key product or service when all of the input capabilities are in use. The SMEs then score the overall performance when a particular capability is removed as an input but all others remain, indicating the "swing" from best case to worst case associated with that particular capability. When multiple SMEs are involved, they arrived at an agreed to score through discussion. The difference in the score with and without the input is the criticality of the input. All of the inputs feeding into a key product or service are scored in this way and the results are combined using the PALMA™ model, enabling the comparison of the relative impact of each individual input on the key product or service or on any node in the value tree.

Identification of Unmet Needs

One of the last steps in the value tree elicitation sessions was to identify and discuss any unmet needs that had not already been uncovered during the elicitation. Unmet needs did not always surface during value tree development and evaluation because the value tree reflects only satisfaction with current (2013) data sources to meet needs, but does not necessarily reflect needs for which current (2013) data sources are completely inadequate or nonexistent. Capturing these provided valuable inputs into the requirements development process. The project team subsequently referred to unmet needs to formulate draft user requirements for use in the requirements elicitation process.

Performance / Satisfaction Scale		
100	Ideal	Meets all requirements and exceeds some
90	Fully Satisfied	Meets all requirements
80	Good	Meets all major requirements with minor limitations
70		
60	Fair	Meets most major requirements, with significant limitations
50		
40	Poor	Fails to meet many major requirements, but provides some value
30		
20	Very Poor	Fails to meet most major requirements, but provides minor value
10		
1	No Capability	Provides no value

Figure 2.   Performance / Satisfaction Scale.

Verification of Value Tree Information

The last step in the value tree elicitation process is the verification of the information collected and the results of the impact analysis from PALMA™. Although the project team typically immediately resolved questions identified during PALMA™ model building, this step affords the SMEs and the project team an opportunity to mutually resolve any remaining questions. For the pilot project, this step was executed with only a small number of the SMEs early on simply to demonstrate the step. This step will be substantially more important in the longer-term NLIR Project when full sets of requirements will be developed and users will also be asked to establish priorities among their needs.

User Requirements Development and Elicitation

The development of the value tree and the collection of information on the relative criticality of the various inputs to a key product or service provide a snapshot in time of the current (2013) capability placed in the context of high-level organizational strategy and goals. The activity to this point mirrors similar ongoing work by NOAA (Ries, V., and Yapur, M., National Oceanic and Atmospheric Administration, oral commun., 2013) and in the National Strategy for Civil Earth Observations (Office of Science and Technology Policy, 2013) [evaluated by the Societal Benefit Area (SBA) instead of organization], while offering some refinements. The subsequent challenge is to pivot to a requirements perspective that is system and solution agnostic and that focuses on the "what" rather than the "how"— the needs and not the solutions.

The field of requirements engineering acknowledges many types of requirements including functional and nonfunctional requirements, system, subsystem, and component requirements, design requirements, interface requirements, and so on (Young, 2004). The focus of the pilot project, and of the NLIR Project as a whole, is to document user requirements for land imaging and, specifically for this report, moderate resolution land imaging. User requirements are the specification of the characteristics of Earth observation data or measurements by a user for a particular application.

The pilot project defined three types of user requirements: (1) threshold; (2) breakthrough; and (3) target, as defined below.

☐ Threshold Requirement—The minimum requirement to be met to ensure that an Earth observation (EO) dataset or service is useful. Below this minimum, the benefit derived does not compensate for the additional cost involved in using the dataset or service.

□ Breakthrough Requirement—An intermediate requirement level between threshold and target which, if achieved, would result in a substantial improvement for the targeted application. The breakthrough level may be considered to be optimum from a cost-benefit point of view when planning, designing, or creating an EO dataset or service.

□ Target Requirement—The value above which further improvement of the EO dataset or service would provide only limited improvement in performance for the application in question. The cost of improving the dataset or service beyond the target requirement would not be matched by a corresponding benefit.

The information acquired for the NLIR Project will use a well-defined standardized taxonomy adopted from the National Aeronautics and Space Administration (NASA) Global Change Master Directory (GCMD) that provides a topic/term/variable framework for defining observable parameters (Olsen and others, 2013). Requirements related to 35 unique GCMD variables were captured in the pilot project (table 2).

Table 2. Global Change Master Directory variables used to document requirements identified in the pilot project and the number of total requirements (threshold, breakthrough, and target) documented against each.

Global Change Master Directory Variables	Number of Requirements	Global Change Master Directory Variables	Number of Requirements
Albedo	3	Soil classification	2
Biomass	2	Soil disturbance	2
Burn severity	4	Soil moisture / water content	5
Cloud presence	2	Sulfur dioxide	4
Dust / ash / smoke	4	Surface reflectance	5
Eruption dynamics / lahars and debris flow	1	Surface water extent	13
Eruption dynamics / pyroclastic flow	2	Top of atmosphere reflectance	2
Eruption dynamics / lava speed / flow	2	Tree cover canopy	1
Land cover	3	Vegetation condition	34
Land surface elements	10	Vegetation cover	6
Land surface temperature	11	Vegetation disturbance	6
Land use classes	13	Vegetation species	25
Lava flow temperature	2	Vegetation type	1
Leaf Area Index (LAI)	2	Volcanic activity	2
Mineral type	10	Volcanic deposits	3
Nonphotosynthetic vegetation	5	Wetland classification	1
Salinity	1	Wildfires	1
Seasonally frozen ground	1		

To the degree possible, the team attempted to consistently assign GCMD variables to needs for similar information, while at the same time trying to take out ties to particular observing technologies. For instance, applications that rely upon some type of vegetative index more fundamentally need information about vegetation condition. Vegetation condition can be assessed using multispectral band differencing, but also can be obtained in other ways, so that the requirement can be more broadly written as a need for vegetation condition, not specific to the Normalized Difference Vegetation Index (NDVI) or some other vegetative index.

Within the Earth observation community, requirements typically are described using an environmental observing attribute such as spatial resolution, sampling frequency, area of coverage, or accuracy. In the pilot project, the primary attributes elicited were geographic coverage, horizontal

resolution, frequency of observation or revisit time, length of data record (importance of continuity/calibration), and data latency. The team also explored accuracy as an attribute with SMEs during elicitations; however, SMEs generally were not able to specify accuracy attributes in a tangible way. The team will explore and develop additional techniques for eliciting accuracy information and other attributes for the NLIR elicitation documentation and associated effort.

Although it was difficult to remain system agnostic in elicitation discussions exploring needs for particular spectral bands, the project team gathered needs in this area as well.

The following sections describe the use of value tree information to prepare preliminary requirements, the elicitation process, and verification and validation of the requirements.

Use of Value Tree Information to Prepare Preliminary Requirements

The data collected in value tree elicitation supports the preparation of a preliminary set of threshold requirements in several ways. First, the value tree identifies where moderate resolution imaging plays a role and the relative criticality of that role. Second, the data highlight areas of weak performance or lower overall satisfaction and the value tree can indicate where improvement would produce the largest overall improvement in performance. Third, the unmet needs identified by the SMEs in the value tree elicitation often point to potential moderate resolution imaging requirements.

By organizing the requirements within the same value tree construct, the requirements are traceable through mission service areas upward to departmental strategic goals, thus establishing the validity of the requirements for the organization.

Using the information from the value tree elicitation and analysis of the PALMA™ model output, the project team developed a preliminary set of threshold requirements and entered them in a requirements collection worksheet for use in the elicitation session with the SMEs. Where information on unmet needs pointed to them, the team developed possible breakthrough and target requirements and entered them in the worksheet as well.

Requirements Elicitation

After preparing a set of preliminary requirements, the project team met again with the SMEs to review the draft list, fill in missing information, and better understand the requirements. To date, this is generally as far as the team was able to proceed with the SMEs in the pilot project—essentially a first review of the draft requirements.

Going forward the team will need to further develop the details of each requirement, particularly for each of the primary attributes. To do this the project team intends to rely on a more free-form variation of a standard knowledge and requirements elicitation technique known as laddering (Corbridge and others, 1994; Chen and others, 2002). The laddering technique does not rely on a survey or questionnaire with a set of questions but rather follows the threads generated by answers to questions of the type "how can you tell that…" and "explain what you mean by…" and asks similar explanatory questions until each thread has been unpacked to a clearly understood level.

The project team documented the results of the preliminary discussions in an extensive spreadsheet that has been distilled to the shorter form accompanying this report. In many cases, the narrative explanation of needs requires further analysis to translate into specific numeric values for requirements attributes.

Requirements Verification

Verification of requirements is the determination that the recorded requirements have been documented accurately—the "requirements are right." This step typically involves a review by the

SMEs to ensure the requirements analysts have captured the stated requirement accurately. The representative sample of moderate resolution imaging requirements at the center of this report were only verified by their respective SMEs in a very preliminary sense. Additional verification steps will be required once the requirements are more fully developed.

Requirements Validation

Validation of requirements is the determination, often through a high-level formal review and approval process, that the stated requirements are correct and complete—the "right requirements." Because of the limited time available in the pilot project, and the fact that the requirements captured still require further development to be fully verified, formal validation was not possible. In addition, the approach to be used for validation has not yet been determined and will be the subject of discussion with the wider NLIR Project team before process implementation.

Survey of State Geospatial Liaisons

In addition to the requirements elicitation process described above, the pilot project completed an informal survey of liaisons in the USGS Geospatial Liaison Network. The liaisons are Federal employees housed in National Spatial Data Infrastructure (NSDI) Partnership Offices across the Nation. The liaisons represent and coordinate National Geospatial Program (NGP) initiatives in state, local, and other Federal agencies, cultivate and maintain long-term relationships, and develop partnerships and supporting agreements. Among other duties, the relevant functions of the liaisons include the following:

- ☐ Advise and consult on geospatial data and technology.
- ☐ Coordinate through and support the statewide coordinating councils that include representation and participation from all sectors within the state.
- ☐ Coordinate with state and local governments.
- ☐ Provide a leadership role in coordinating with Federal agencies in states or regions.
- ☐ Seek opportunities to create relationships and collaborate with tribes.
- ☐ Seek partnerships with not-for-profit organizations, the private sector, universities, and consortia.
- ☐ Advise and consult with USGS disciplines to maximize their participation in NGP programs and the NSDI.
- ☐ Support emergency operations/homeland security activities.
- ☐ Serve on-site at specific Federal agencies to ensure strong USGS science and emergency operations linkages.

The USGS Geospatial Liaison Network is the "local face" of the USGS NSDI and NGP programs and, for the pilot project, provided insight into the various applications of land remote sensing in general and moderate resolution imagery in particular across the states. The pilot project sought to obtain a general sense of the uses of moderate resolution imagery among the supported state, local, and tribal governments, academia, and the private sector and to assess the need for and potential value in more detailed, formal elicitations of these groups.

Coordination and Preparation

To maximize the information collected while minimizing the effect on liaison workload, the project team contacted the NGP Partner and User Engagement Liaison Coordinator to coordinate the

best approach to the interviews and to review the proposed questions and information to be provided to the liaisons in advance of the telephone discussions. Taking advantage of a regularly scheduled liaison coordination teleconference, the project team provided an overview of the project and answered questions about the information to be gathered and the application of the information. The team subsequently contacted a select number of liaisons to review and refine the questions and prepared a brief set of Frequently Asked Questions. The Partner and User Engagement Liaison Coordinator then sent the information to all of the liaisons to begin the interview process.

The list of questions used in the interviews is shown in Appendix 2. Survey of State Geospatial Liaisons.

Telephone Interviews

Once the liaisons had received the project information and interview questions, the project team completed telephone interviews with them. The team interviewed 31 of the 34 liaisons with most interviews lasting 30 to 40 minutes and some interviews lasting as long as 2 hours.

Generally two members of the project team participated in the interview with each liaison and gathered notes on the answers to the questions and any other related discussion. The notes have been collected and analyzed to summarize the results. The results of this informal survey provide supplemental information for the more formal elicitation process and the relevant results are highlighted in the analysis below.

Summary of Results

The liaisons identified 10 primary application areas supported by remote sensing within their states as well as the subset of applications that relied on moderate resolution imagery (see fig. 3). A more detailed review of the initial results of the liaison interview analysis will be provided within the final NLIR Project deliverables. This effort was preliminary in preparation for NLIR and was used to obtain enhanced understanding from USGS partners on potential land imagery use.
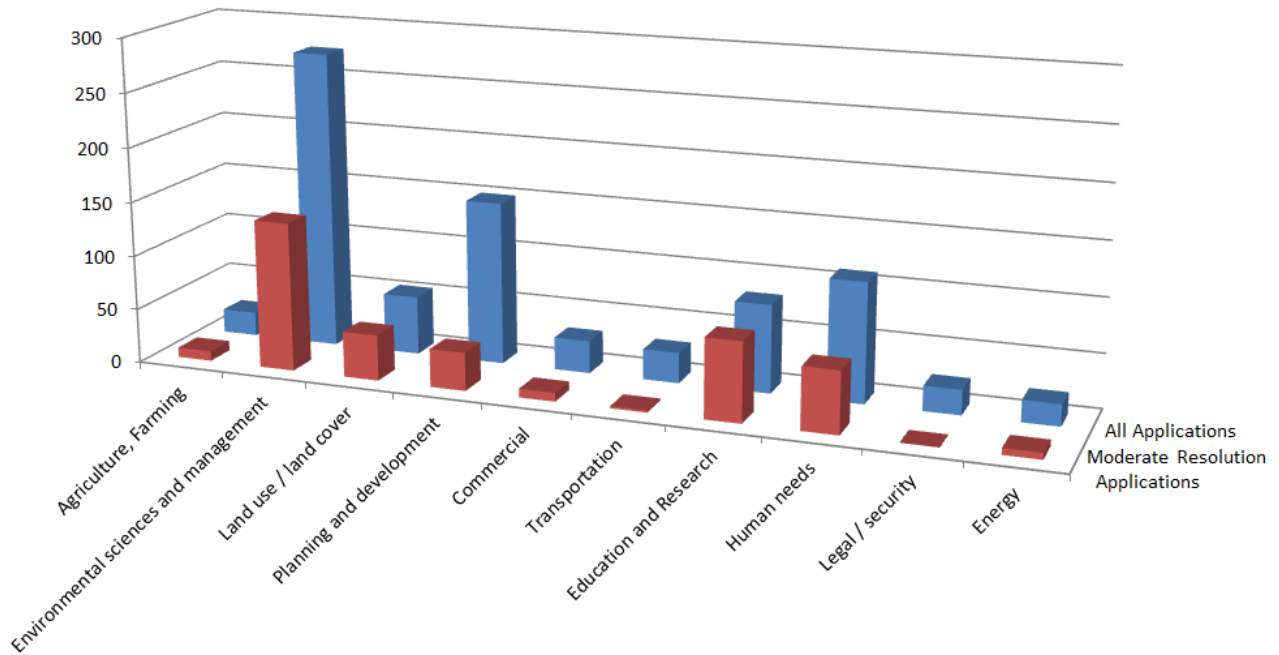
Figure 3. Summary of applications identified by the State Geospatial Liaisons supported by moderate resolution imagery (red) and by all types of remote sensing (blue).

Results and Analysis

The results for the pilot project are presented in two parts. The "Value Tree Analysis—Evaluation of Current (2013) Use" section contains the results of the value tree analysis, which reflects an evaluation of subject matter expert inputs regarding the relative criticality and performance of current (2013) sources of moderate resolution imagery. The results have been documented in two ways to illustrate the flexibility of the process to support analysis in different frameworks. The team chose to align each of the key products or services to user-specific application areas as well as to SBA constructs. Both results are presented.

The second part of the results section, "User Requirements—A Preliminary Set", contains summary information about the requirements elicited and documented in the pilot project.

Value Tree Analysis—Evaluation of Current (2013) Use

The project team organized the set of key products or services into application areas to facilitate analysis (table 3). The alignment of key products or services to application areas, along with the primary corresponding organization from which subject matter expert(s) were engaged also is shown.

The assignment of key products or services to application areas was somewhat subjective and, in many cases, a particular product could have been assigned to any of several application areas. In these cases of multiple possible application areas, the team used their best judgment to assign a reasonable placement.

Table 3.   National Land Imaging Requirements pilot project application areas, key products or services, and the organization consulted.

Application Area	Key Products	Subject Matter Expert Organization
Agriculture	Actuarial rate maps	Risk Management Agency[1]
	Compliance monitoring investigations	
	Pasture rangeland insurance	
	Global crop area estimation	Foreign Agricultural Service[1]
	Global crop yield estimation	
	Rapid response to global agricultural crises	
	NASS area sampling frame	National Agricultural Statistics Service[1]
	National crop forecasting	
	Crop residue monitoring	Agricultural Research Service[1]
	National agriculture disaster response	Natural Resources Conservation Service[1]
	Yield and water use estimates	Agricultural Research Service[1]
Climate and Land Use	Global Land Cover 30-meter Dataset	U.S. Geological Survey[2]
	Irrigation monitoring and research	
	National drought assessment	
	National irrigated lands dynamics	
	National Phenology Assessment (NPA)	
	National land cover change assessment	
	Vegetation Change Tracker (VCT)	
Forestry	Burned Area Emergency Response (BAER) Burned Area Reflectance Classification (BARC)	U.S. Forest Service[1]
	Rapid Assessment of Vegetation Condition (RAVG)	
	Monitoring Trends in Burn Severity (MTBS)	
	Effectiveness of mitigation actions	
	Forest disturbance assessment	
	Forest disturbance queuing	
	Forest resource mapping for inventory and monitoring	
	National insect and disease risk map	
	Digital soil mapping	
	Multiresolution Land Characteristics (MRLC) tree canopy cover	
	Regional scale forest mapping	
Land Management	Detailed vegetation classification	Bureau of Land Management[2]
	Emergency stabilization and rehabilitation plans	
	Local drought assessments	
	Multi-district mapping	
	Sage Grouse conservation	
Mineral Resources	Environmental impact assessments	U.S. Geological Survey[2]
	Mineral deposit modeling	
	Minerals assessment	
Natural Resource Conservation	Conservation plan maps	Natural Resources Conservation Service[1]
	Soil survey interpretation maps	
	Wildlife and landscape initiatives	
	Resource inventories	
Solid Earth Hazards	Hazards communication	U.S. Geological Survey[2]
	Volcano assessment	
	Volcano monitoring	
	Volcano research	
Surface Mining	Contemporaneous reclamation monitoring	Office of Surface Mining[2]
	Monitoring long-term restoration of mined areas	
Water Management	Consumptive water use	Bureau of Reclamation[2]
	National watershed modeling	U.S. Geological Survey[2]
	Riparian vegetation mapping	Bureau of Reclamation[2]
Wildlife/Ecosystems	Ecosystem carbon assessment	U.S. Geological Survey[2]
	Global ecosystem mapping	
	Migratory bird surveys and management plans	U.S. Fish and Wildlife Service[2]
Intermediate Products	LANDFIRE existing vegetation products	U.S. Geological Survey[2]
	National Cropland Data Layer (NCDL)	National Agricultural Statistics Service[1]
	National Land Cover Dataset (NLCD)	U.S. Geological Survey[2]

[1]U.S. Department of Agriculture   [2]U.S. Department of the Interior

Application Area Framework—Results and Analysis

The following figures demonstrate some of the possible ways in which results from this type of analysis might be presented. For this analysis all application areas were assumed to be equally weighted. "Impact," as used within the PALMA™ model, is a measure of the relative criticality of a given data source as evaluated in the application area at a given node in the value tree if that data were removed as an input source. The "impact" to an application area is the summation of all of the incremental impacts of removing those individual inputs at all relevant nodes of the value tree. The impact is a relative number, not equivalent to a percentage, but useful as a means of comparison to the relative impact of other elements.

A summary of the relative impact of moderate resolution data (aggregate impacts from all sources) on each of the application areas is shown in figure 4. Note that all of the application areas are affected to some extent because the pilot project intentionally elicited data from activities that use moderate resolution data.

National Land Imaging Requirements Pilot Project Moderate Resolution Relative Impact by Application Area
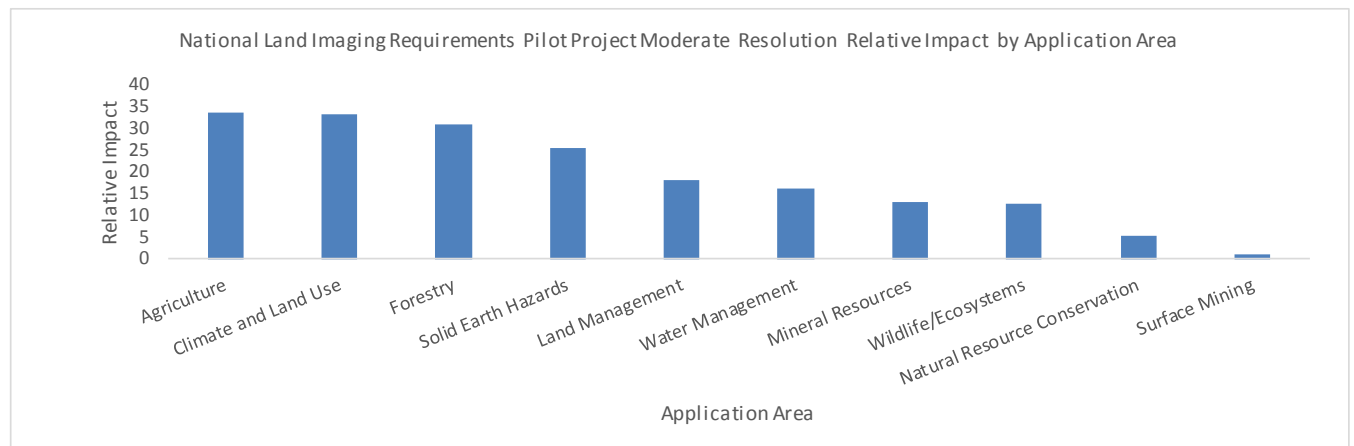
Figure 4.   The relative impact of moderate resolution data on each of the application areas.

The relative impact of each spectral band on each application area can be conveyed in two different ways. The overall impact of each spectral band across all application areas is shown in figure 5, with the relative contributions of each area reflected in the colored segments of each bar. Conversely, Figure 6 shows the relative impact of each spectral band within each application area.

The impact of each spectral band from moderate resolution sources across all of the application areas is summarized in figure 7.
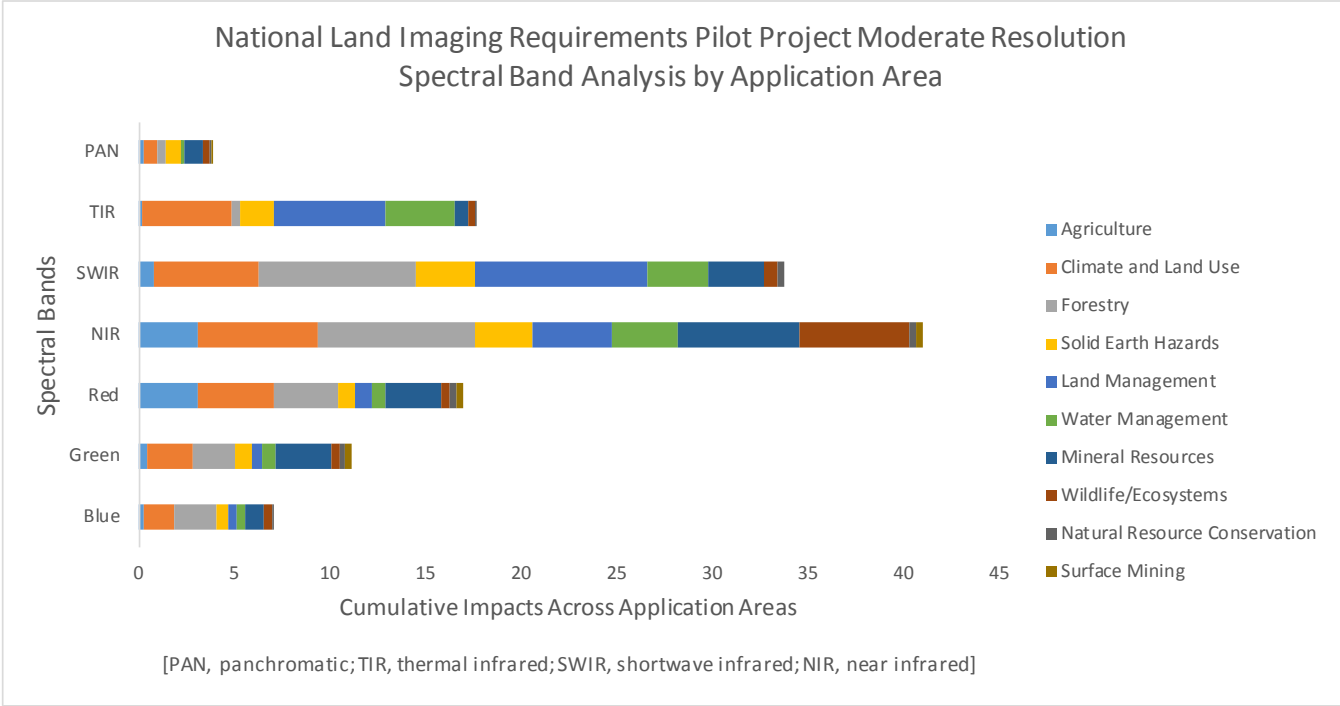
Figure 5. Cumulative impact of each of the spectral bands from moderate resolution sources across the application areas. From this graphic, one can get a sense of which bands overall have the greatest impact and which bands have the least impact.
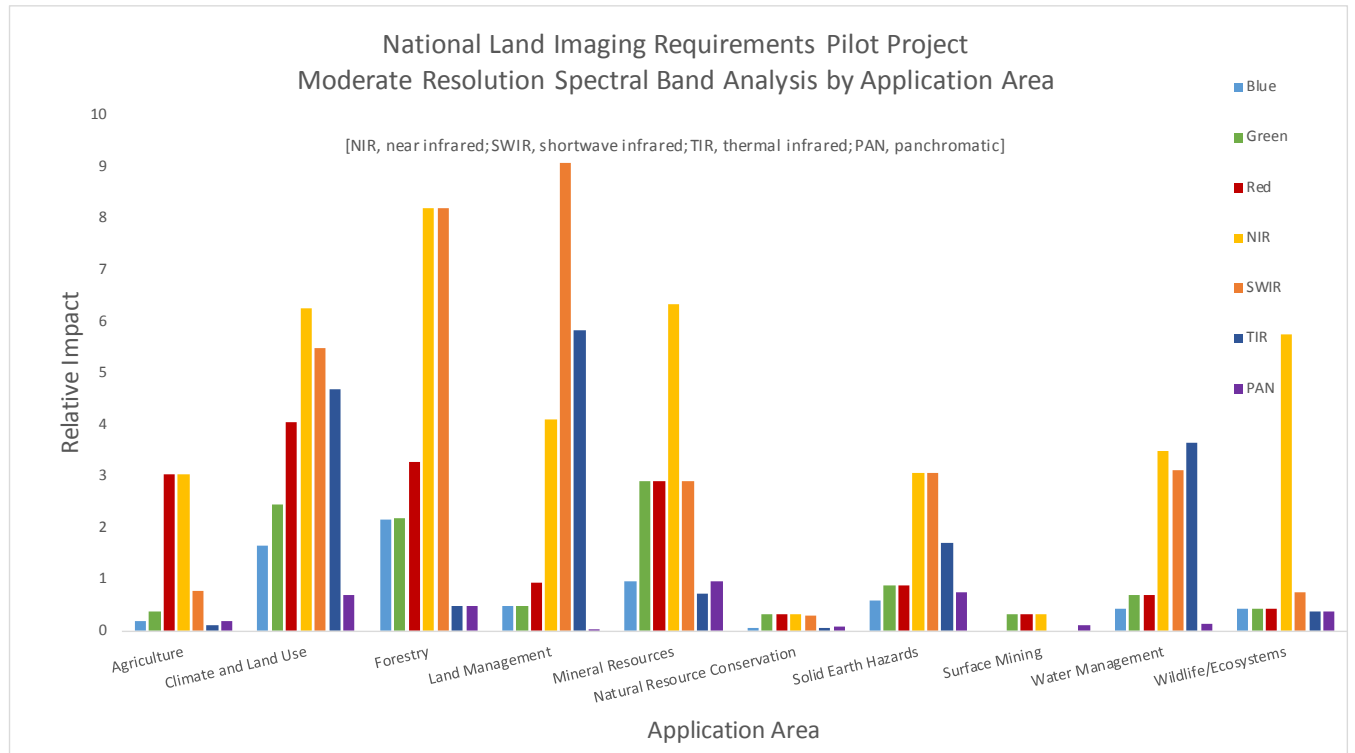
Figure 6. Impact of each of the spectral bands from moderate resolution sources within each application area. This presentation of the data provides a picture of which application areas are the heaviest users of moderate resolution imagery, and how similar or unique the individual application areas are in their use of the various bands.

National Land Imaging Requirements Pilot Project
Relative Impact of Spectral Bands across all Application Areas

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic]
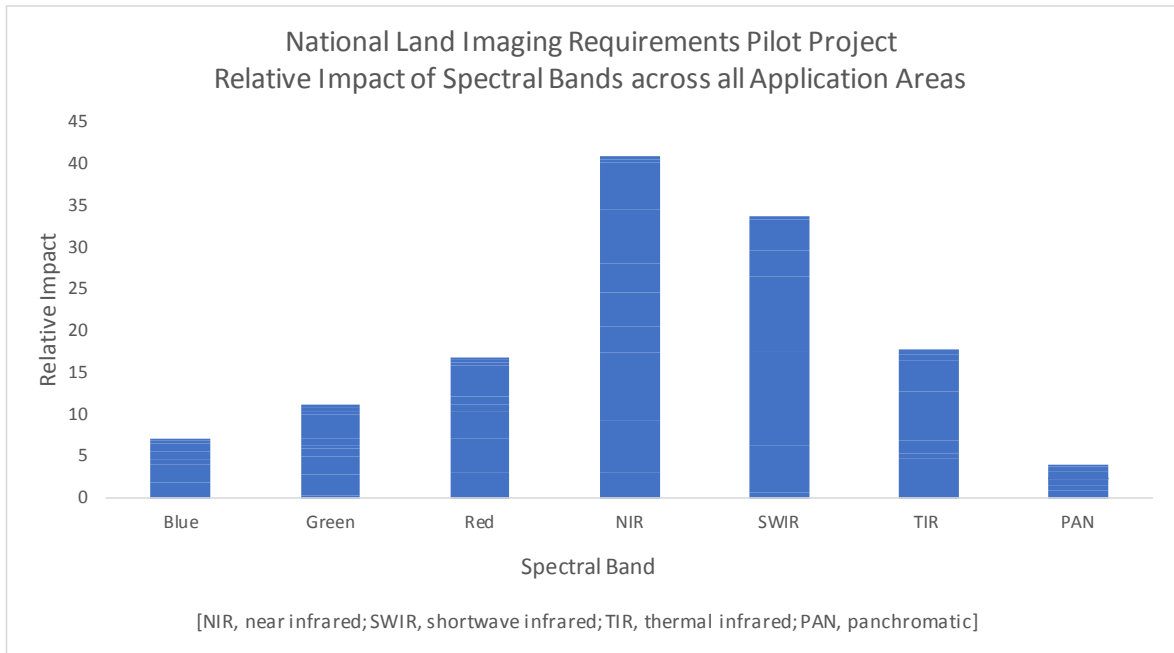
Figure 7. Impact of each of the spectral bands from moderate resolution sources across all of the application areas. From this graphic, one can to see that the NIR band has the greatest impact and the PAN band has the least impact.

Societal Benefit Area Framework—Results and Analysis

To generate the same analysis from a SBA perspective, the project team assigned each of the key products or services to the six relevant SBAs. The team used the SBA definitions established in the National Strategy for Civil Earth Observations. The definitions are in Appendix 3. Societal Benefit Area Definitions. The SBAs determined to be relevant for the pilot project were agriculture and forestry, climate, disasters, ecosystems, energy and mineral resources, and water resources.

The assignment of key products or services to SBAs was somewhat subjective and in some cases an individual key product or service could reasonably be assigned to more than one SBA. In those cases, the team applied its analytical expertise. Additionally, because the analysis also is based on a limited sample of data, the results should only be used as illustrative of what the impacts look like within an SBA framework, not a definitive analysis.

A summary of the relative impact of moderate resolution data (aggregate impacts from all sources) on each of the SBAs is shown in figure 8.
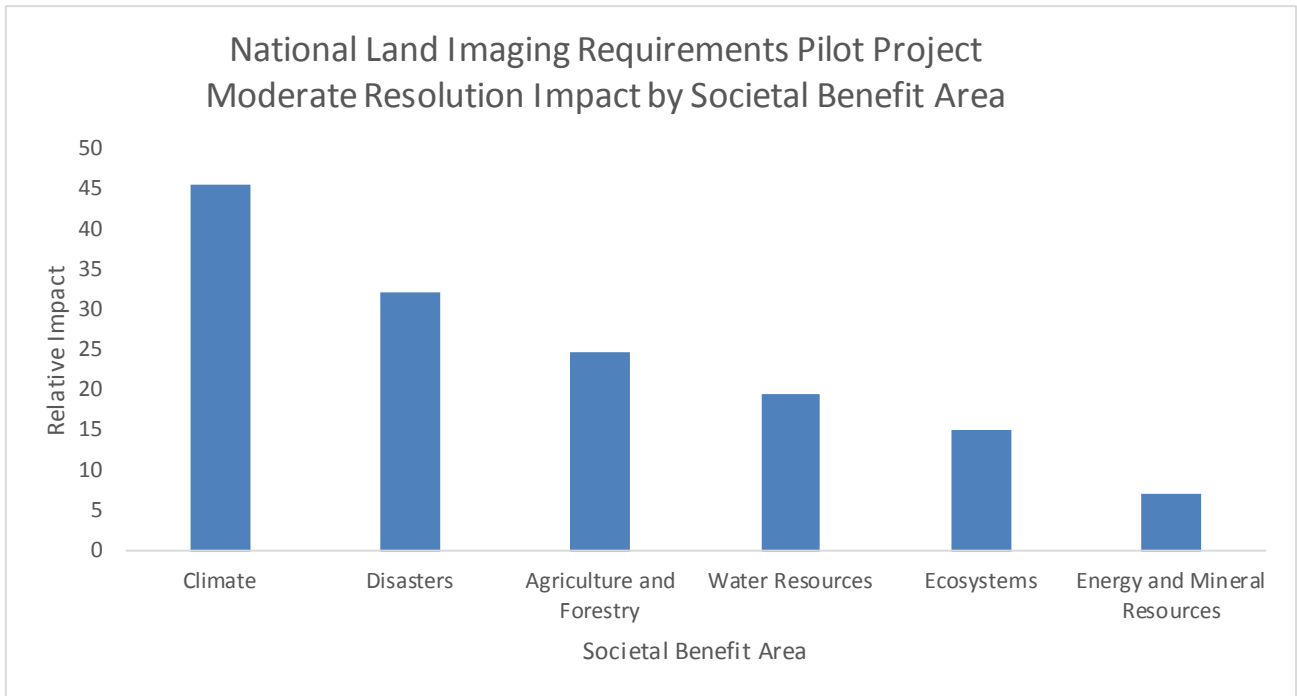
Figure 8. The relative impact of moderate resolution data on each of the Societal Benefit Areas.

The overall impact of each spectral band across all SBAs is shown in figure 9, with the relative contributions of each SBA reflected in the colored segments of each bar. Conversely, figure 10 shows the relative impact of each spectral band within each SBA.
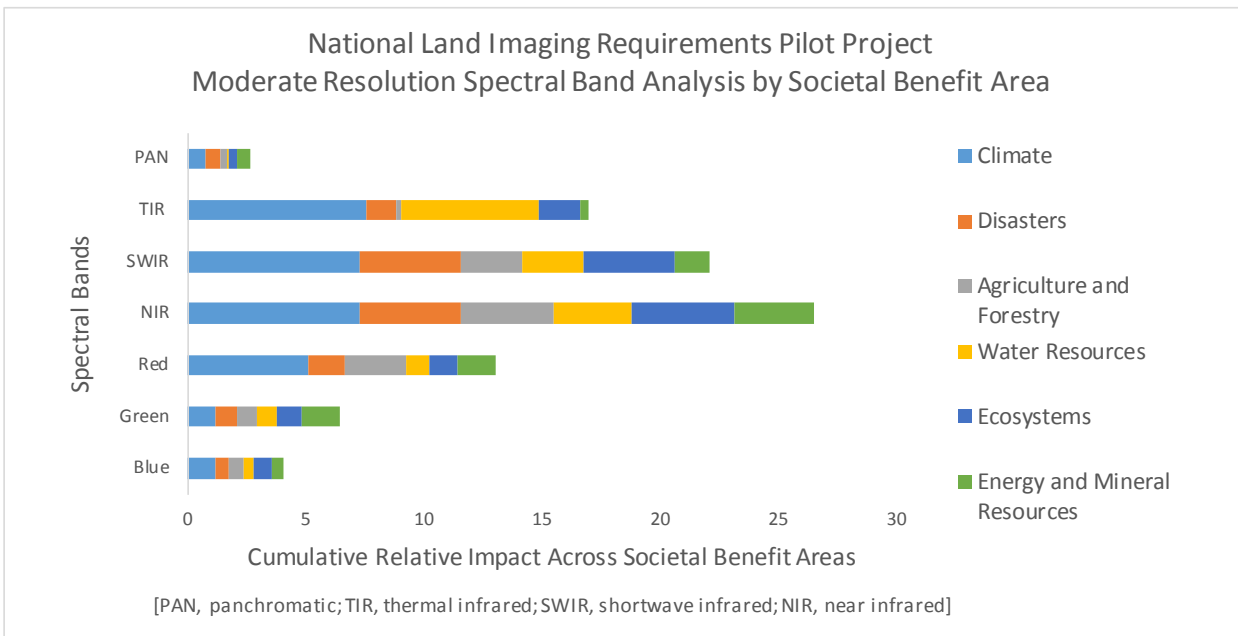
Figure 9. Cumulative impact of each of the spectral bands from moderate resolution sources across the societal benefit areas.

To provide a comparison, the team slightly refined the results presented in the 30 May "early deliverable" for the pilot project, which provided an analysis of the relative criticality of each of the spectral bands across all SBAs from a previous value tree analysis. The corresponding spectral band analysis from the earlier study is shown in Figure 11.
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National Land Imaging Requirements Pilot Project
Moderate Resolution Spectral Band Analysis by Societal Benefit Area

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic]
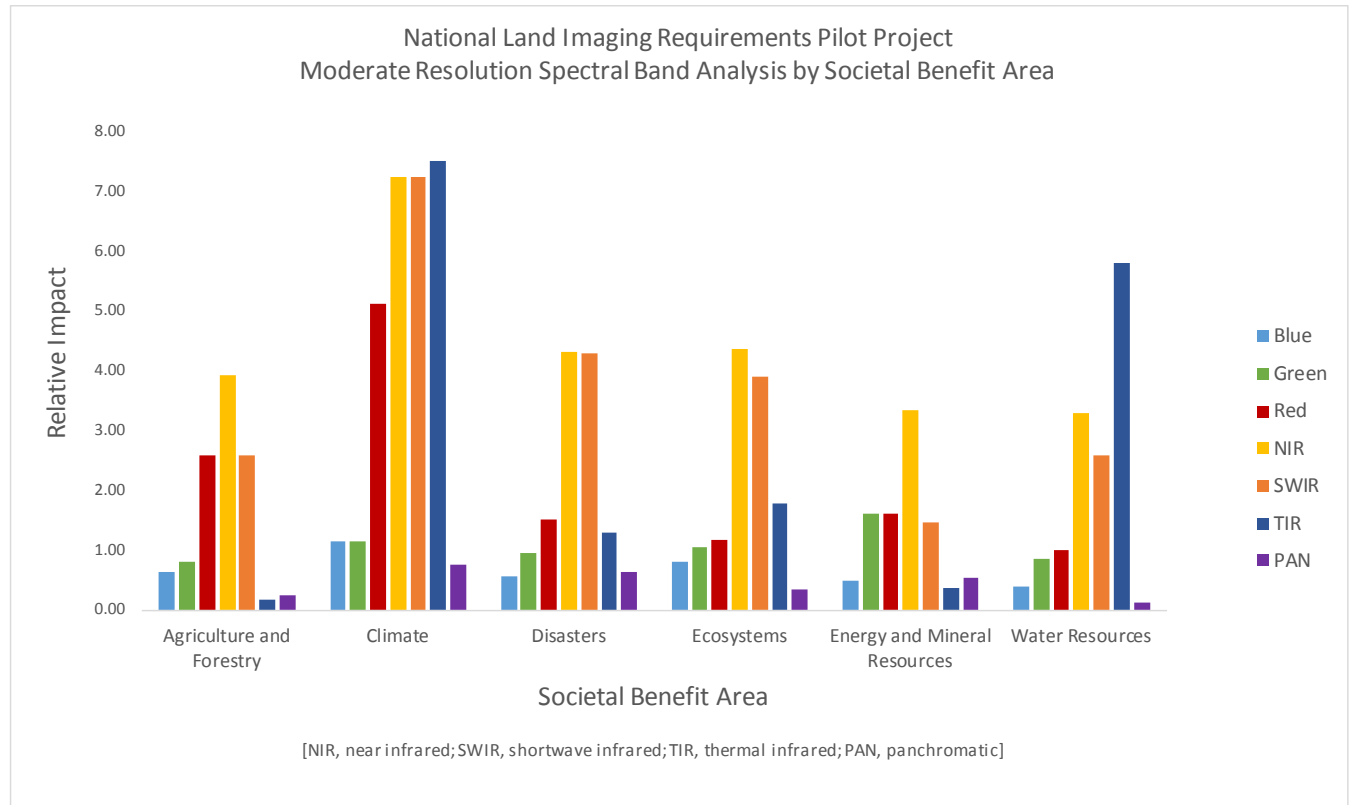
Figure 10. Impact of each of the spectral bands from moderate resolution sources within each SBA. This presentation of the data provides a picture of which SBAs are the heaviest users of moderate resolution imagery, and how similar or unique the individual SBAs are in their use of the various bands.

The scales reflected in the horizontal axes of Figure 9 and Figure 11 both showing relative impact, are quite different owing to two separate factors. First, the scope of the earlier analysis covered the gamut of Earth observing systems, such that moderate resolution multispectral imaging systems were only a small component (one among many), and therefore the impact within and across SBAs was much lower. Second, the pilot project focused on applications with known uses of multispectral imagery so the impact would be expected to be much more substantial for the chosen applications. The higher relative valuing of the thermal infrared band also likely is due to the focused nature of the pilot project. Although the scales shown are quite different, one can easily see that the relative impacts of the individual spectral bands are fairly consistent and overall the two analyses yielded fairly similar results. This outcome is not unexpected as the uses of moderate resolution multispectral imagery tend to support like applications (land cover and vegetation indices, for example). The impact of each of the spectral bands from moderate resolution sources across all of the SBAs is summarized in figure 12.
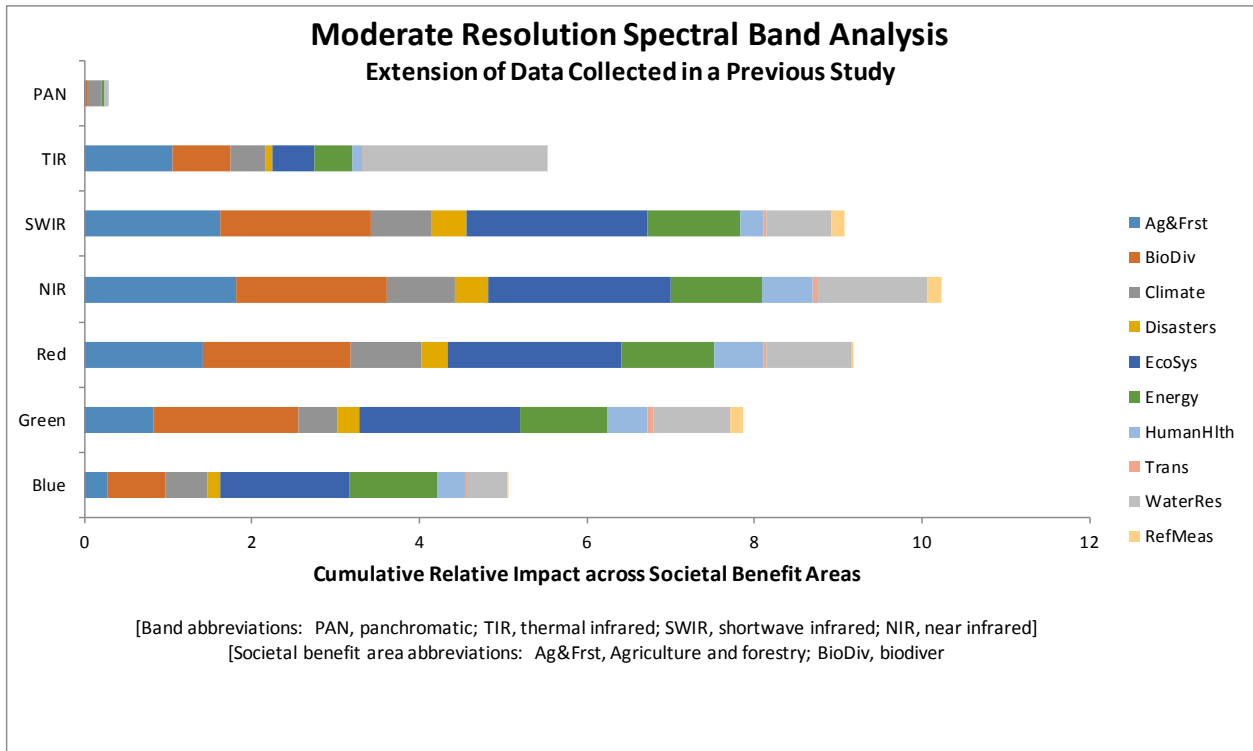
Figure 11. Extending data from a previous Portfolio Analysis Machine™ analysis, this figure shows the cumulative impact of each of the spectral bands from moderate resolution sources across the societal benefit areas.
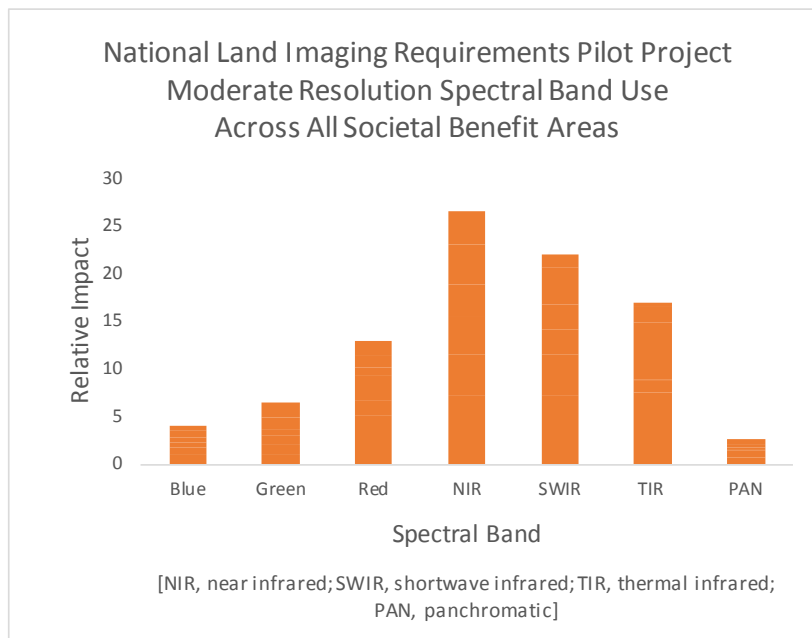

Figure 12. Impact of each of the spectral bands from moderate resolution sources across all of the societal benefit areas. From this graphic, one can see that the near infrared band has the most impact and the panchromatic band has the least impact.

User Requirements—A Preliminary Set

The requirements elicitation part of the pilot project yielded a total of 191 user requirements, including 114 threshold requirements, 62 breakthrough requirements, and 15 target requirements (shown as a percentage in Figure 13). A summary of all requirements collected are contained in Appendix 4, Preliminary User Requirements Summary Information.
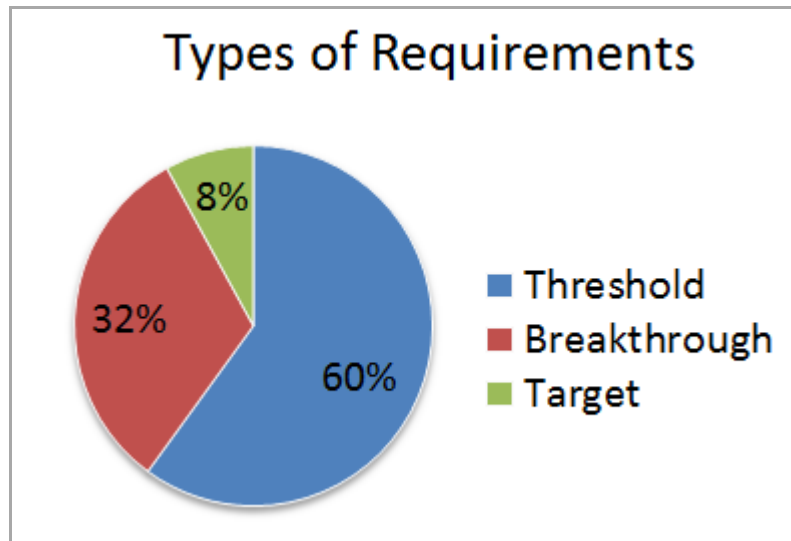
Figure 13. National Land Imaging Requirements pilot project user requirements summary by requirement type.

Of the 191 requirements, a total of 158 could be met or partially met by moderate resolution data. In cases where the resolution of a threshold requirement was specified as being greater than 120 m (outside of our definition of moderate resolution) but where the breakthrough or target resolution for that same requirement was specified as being between 5 and 120 m, the set of requirements was determined to be in scope for the project and are included in this summary.

Some requirements were only developed at the threshold level. In these cases, meeting the threshold completely satisfies the need stated by the user, and any improvements to resolution, frequency, or spectrum were determined not likely to have a substantial impact on key product or service performance.

A few of the requirements captured represent the need for a derived product, such as Land Use Classes, rather than a need for EO data. The needs of downstream users of moderate resolution data represent an important set of use cases, so the team was fortunate to be able to capture a few of those types of requirements to work through the process.

Geographic Coverage

Specific information about the geographic coverage required to meet each requirement was gathered in the elicitation, however, for the purpose of this report, geographic coverage has been loosely binned into the four categories shown in Figure 14. The category "Targeted" represents cases where geographically focused, limited duration information is required, such as for disaster response or the periodic need for imagery to support surface mining compliance monitoring at individual mine sites. The category "U.S." also includes requirements that extend to Puerto Rico and U.S. island territories.

In Figure 14, the high percentage of requirements with coverage limited to the United States simply reflects the user groups included in the pilot project elicitation. Many of the DOI and USDA subordinate organizations have responsibilities that are limited to the United States and its territories, and therefore they do not require global coverage.
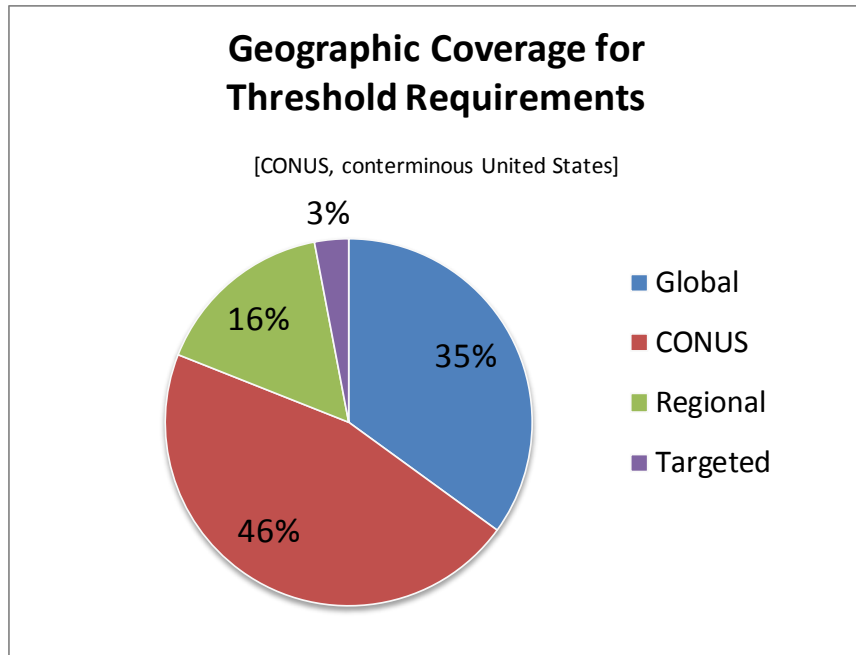
Figure 14. Percentage of threshold requirements in each of the four geographic coverage categories indicated.

Horizontal Resolution

Similarly, for the purpose of this report horizontal resolution for each requirement was binned into one of seven categories: < 5 m, 5 m, ≤15 m, ≤30 m, ≤60 m, 100 m, and >100 m as shown in figure 15. Again, the large proportion of requirements that can be met by data with horizontal resolutions of 30 m or less reflects the choice of target applications in the pilot project.
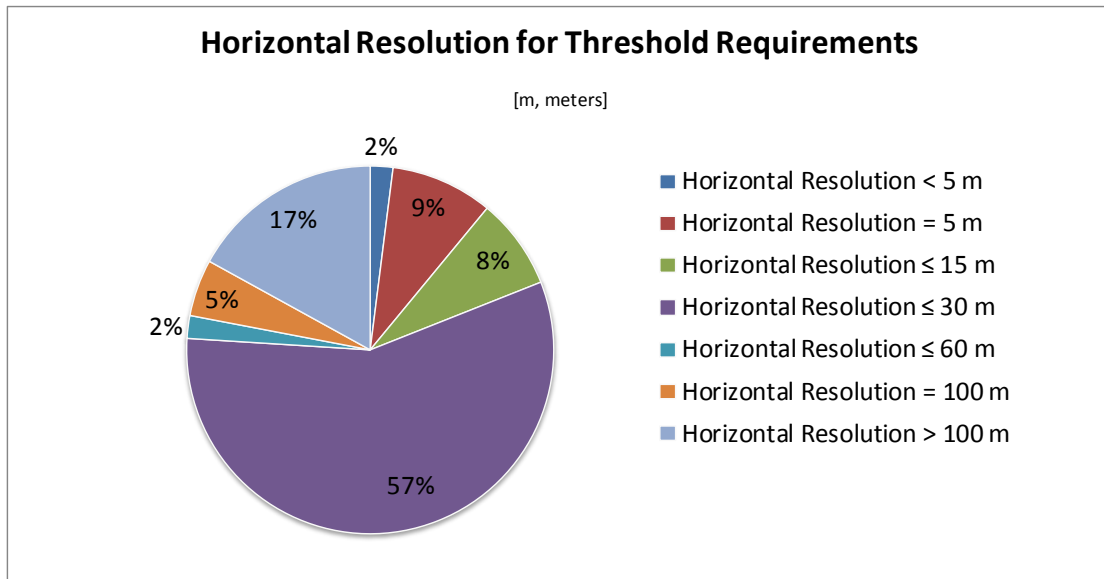
Figure 15.   Percentage of threshold requirements in each of the seven horizontal resolution categories indicated. Fifty-seven percent of the threshold requirements can be met by data that are 30 meters or less in resolution.

Revisit Frequency

In documenting user requirements, the team tried to gather information in terms of the need for data refresh at some frequency to deliver the key products or services rather than asking users to speculate what frequency of satellite overpass would yield cloud-free imagery to support their activities. For the purposes of this report, however, the team loosely binned the need for data refresh into the following categories:

☐ 2-day revisit: Cloud-free data needed daily or every few days
☐ 4-day revisit: Cloud-free data needed weekly
☐ 8-day revisit: Cloud-free data needed every couple of weeks
☐ 16-day revisit: Cloud-free data needed seasonally
☐ 16-day revisit: Cloud-free data needed annually or longer

The summary of revisit frequency for the set of threshold requirements using a further roll-up of the categories listed above is shown in figure 16.

Overall, 36 percent of all threshold requirements collected require less than an 8-day revisit. These data refresh needs are primarily related to applications requiring observation of plant phenological cycles during the growing season, the need to see vegetation disturbance and response in a timely manner, estimation of evapotranspiration and drought monitoring, and disaster response.

Revisit Frequency for Threshold Requirements

- Revisit Frequency < 2 days
- Revisit Frequency ≤ 4 days
- Revisit Frequency = 8 days
- Revisit Frequency ≥ 16 days
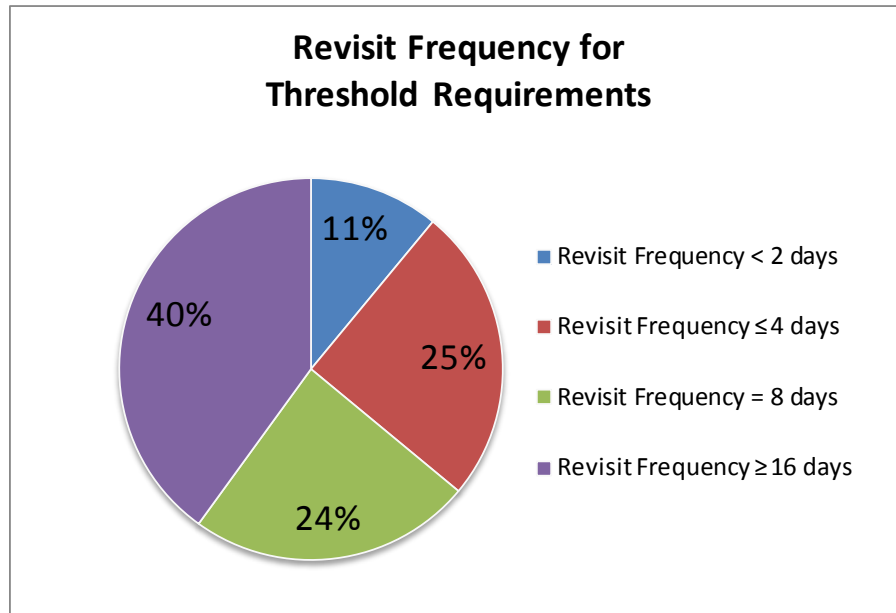
Figure 16. Revisit frequency for the 114 threshold requirements identified in the pilot project.

Spectral Needs

The need for thermal infrared data was identified in 36 percent of all requirements documented in the pilot project; however, this finding likely underestimates the need for thermal infrared data because thermal data are used to identify and remove clouds from applications using visible, near infrared (NIR) and shortwave infrared (SWIR), though not consistently called out directly. Only 14 percent of all requirements can be met by visible and NIR data alone.

Although roughly 13 percent of SMEs indicated any use of the panchromatic (PAN) band data at the threshold level (and that was often reported as sporadic/experimental), some did indicate a desire to exploit those data more fully in the future for PAN sharpening.

Several applications identified either additional parts of the spectrum that needed to be sampled, or greater spectral resolution within existing bands.

- ☐ To estimate crop residue (nonphotosynthetic vegetation), additional spectral bands are needed in the SWIR portion of the spectrum. Ideally, the additional bands would be 10–50 nanometers (nm) wide, centered at 2030 nm, 2100 nm, and 2200 nm. The 2100 nm band exhibits the cellulose absorption feature, with the two other bands on the shoulders. Some research (Daughtry, C., U.S. Department of Agriculture Agricultural Research Service, written commun., 2013) has evaluated the SWIR bands that successfully operated on the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite for this purpose (the SWIR sensor on ASTER stopped functioning in 2008).
- ☐ Adding a 7-micron thermal infrared (TIR) band would make sulfur dioxide (SO_2) and volcanic ash mapping with Landsat data possible, enhancing global aviation safety. Ultraviolet (UV) bands also are needed for mapping SO_2 in the atmosphere.

Horizontal Resolution, Revisit, and Spectral Needs Combined

Combining the attributes of resolution and revisit, of the threshold requirements netted by the pilot project, exactly 50 percent (57 requirements) can currently (2013) be met by 30-m resolution imagery at an 8-day revisit (current 2013 Landsat capability), whereas dropping to a 16-day revisit would meet only 22 percent of the requirements. A summary of these requirements by key product is provided in table 4.

Similarly, without regard for revisit frequency, 57 percent of the threshold requirements (65 requirements) can be met by data with a resolution of 15 m and any combination of visible and near infrared (VNIR) or SWIR bands (similar to Satellite Pour l'Observation de la Terre (SPOT) capability), however, dropping the SWIR band (similar to Disaster Monitoring Constellation (DMC) capability) would meet only 13 percent of the threshold requirements (15 requirements). This comparison is shown in table 5.

Sustaining the Long-Term Calibration

Landsat provides a unique dataset in the form of a 40-year calibrated record of the surface of the Earth (U.S. Geological Survey, 2013). Subject matter experts were not consistently asked in the pilot project elicitation about the importance of having a calibrated long-term record to support their activities. But the team did note the length of the data record where SMEs indicated it was a relevant factor. As would be expected, applications looking at long-term change were the most vocal advocates of maintaining the record, although many others had well-defined needs for a dataset that goes back at least 3 years. Some specific key products, services, and intermediate products relying upon the calibrated archive include the following:

- ☐ Monitoring Trends in Burn Severity
- ☐ National Land Cover Dataset (NLCD)
- ☐ National Drought Assessment
- ☐ Global Land Cover 30-meter Dataset
- ☐ National Land Cover Trends Assessment
- ☐ National Carbon Assessment
- ☐ National Crop Forecasting
- ☐ Forest Resource Mapping
- ☐ Sage Grouse Conservation
- ☐ Actuarial Rate Maps for Crop Insurance

Table 4. Comparison of threshold requirements met by 30-meter resolution and 8-day revisit and those requirements no longer met if revisit drops to 16 days.

Threshold requirements currently met by 30-meter resolution and **8**-day revisit		Threshold requirements still met if reduced to **16**-day revisit	
Key Product	**Requirement**	**Key Product**	**Requirement**
Irrigation monitoring	Albedo	Irrigation monitoring	Albedo
Consumptive use	Albedo	Consumptive use	Albedo
Ecosystem carbon assessment	Biomass	Ecosystem carbon assessment	Biomass
Burned Area Emergency Response (BAER), Reflectance Classification (BARC)	Burn severity	Burned Area Emergency Response (BAER), Reflectance Classification (BARC)	Burn severity
Monitoring Trends in Burn Severity (MTBS)	Burn severity	Monitoring Trends in Burn Severity (MTBS)	Burn severity
Vegetation Change Tracker (VCT)	Cloud presence	Vegetation Change Tracker (VCT)	Cloud presence
Vegetation Change Tracker (VCT)	Land cover	Vegetation Change Tracker (VCT)	Land cover
National land cover change assessment	Land cover	National land cover change assessment	Land cover
Conservation map plans	Land surface elements	Conservation map plans	Land surface elements
Crop yield	Land surface temperature	Yield and water use estimates	Land surface temperature
Irrigation monitoring	Land surface temperature	Consumptive use	Land surface temperature
Yield and water use estimates	Land surface temperature	Riparian vegetation mapping	Land surface temperature
Consumptive use	Land surface temperature	Crop yield	Land surface temperature
Riparian vegetation mapping	Land surface temperature	Irrigation monitoring	Land surface temperature
Global ecosystem mapping	Land use classes	Migratory birds and management plans	Land use classes
Ecosystem carbon assessment	Land use classes	Consumptive use	Land use classes
Crop area	Land use classes	National watershed monitoring	Land use classes
Migratory birds and management plans	Land use classes	Global ecosystem mapping	Land use classes
Consumptive use	Land use classes	Ecosystem carbon assessment	Land use classes
National watershed monitoring	Land use classes	Crop area	Land use classes
Yield and water use estimates	Leaf Area Index (LAI)	Yield and water use estimates	Leaf Area Index (LAI)
Soil survey interpretation maps	Minerals type	Soil survey interpretation maps	Minerals type
Actuarial rate maps	Nonphotosynthetic vegetation	Actuarial rate maps	Nonphotosynthetic vegetation
Ecosystem carbon assessment	Salinity	Ecosystem carbon assessment	Salinity
Ecosystem carbon assessment	Soil classification	Ecosystem carbon assessment	Soil classification
Digital soil mapping	Soil classification	Digital soil mapping	Soil classification
Local drought assessments	Soil moisture / water content	Local drought assessments	Soil moisture / water content
Global Land Cover 30-meters Dataset (GLC30m)	Surface reflectance	Yield and water use estimates	Surface reflectance
Yield and water use estimates	Surface reflectance	Global Land Cover 30-meters Dataset (GLC30m)	Surface reflectance
Resource inventories	Surface water extent	Resource inventories	Surface water extent
Landscape analysis and vegetation monitoring	Surface water extent	Landscape analysis and vegetation monitoring	Surface water extent
National Landcover Dataset (NLCD)	Top of atmosphere reflectance	National Landcover Dataset (NLCD)	Top of atmosphere reflectance
LANDFIRE existing vegetation	Top of atmosphere reflectance	LANDFIRE existing vegetation	Top of atmosphere reflectance
Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Tree cover canopy	Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Tree cover canopy
Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Vegetation condition	Local drought assessments	Vegetation condition
Monitoring Trends in Burn Severity (MTBS)	Vegetation condition	Forest disturbance assessment	Vegetation condition
Actuarial rate maps	Vegetation condition	Consumptive use	Vegetation condition
Actuarial rate maps	Vegetation condition	Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Vegetation condition
Irrigation monitoring	Vegetation condition	Monitoring Trends in Burn Severity (MTBS)	Vegetation condition
Local drought assessments	Vegetation condition	Actuarial rate maps	Vegetation condition
Forest disturbance assessment	Vegetation condition	Actuarial rate maps	Vegetation condition
Consumptive use	Vegetation condition	Irrigation monitoring	Vegetation condition
Global Land Cover 30-meters Dataset (GLC30m)	Vegetation cover	Global Land Cover 30-meters data set (GLC30m)	Vegetation cover
Multiresolution Land Characteristics (MRLC) tree canopy cover	Vegetation cover	Multiresolution Land Characteristics (MRLC) tree canopy cover	Vegetation cover
Vegetation Change Tracker (VCT)	Vegetation disturbance	Vegetation Change Tracker (VCT)	Vegetation disturbance
Emergency stabilization and rehabilitation plans	Vegetation disturbance	Emergency stabilization and rehabilitation plans	Vegetation disturbance
Forest resource mapping for inventory and monitoring	Vegetation species	Multi-district mapping	Vegetation species
Regional scale forest mapping	Vegetation species	National insect and disease risk map	Vegetation species
Crop area	Vegetation species	National crop forecast	Vegetation species
Sage Grouse conservation	Vegetation species	Conservation map plans	Vegetation species
Multi-district mapping	Vegetation species	Consumptive use	Vegetation species
National insect and disease risk map	Vegetation species	Forest resource mapping for inventory and monitoring	Vegetation species
National crop forecast	Vegetation species	Regional scale forest mapping	Vegetation species
Conservation map plans	Vegetation species	Crop area	Vegetation species
Consumptive use	Vegetation species	Sage Grouse conservation	Vegetation species
Riparian vegetation mapping	Vegetative cover	Riparian vegetation mapping	Vegetative cover
Volcano monitoring	Volcanic deposits	Volcano monitoring	Volcanic deposits

Left panel vertical label: All threshold requirements currently satisfied by 30-meter resolution and **8**-day revisit

Right panel vertical label: All threshold requirements satisfied by 30-meter resolution and **16**-day revisit

Table 5. Comparison of threshold requirements met by 15-meter resolution and any combination of visible and near infrared (VNIR) and shortwave infrared (SWIR) data, and those no longer met if SWIR is not available.

Threshold requirements currently met by 15-meter resolution and any combination of visible and near infrared (VNIR) and shortwave infrared (SWIR)

Key Product	Requirement
Consumptive use	Albedo
Irrigation monitoring	Albedo
Ecosystem carbon assessment	Biomass
Burned Area Emergency Response (BAER), Burned Area Reflectance Classification (BARC)	Burn severity
Monitoring Trends in Burn Severity (MTBS)	Burn severity
Emergency stabilization and rehabilitation plans	Burn severity
National land cover change assessment	Land cover
Disaster response	Land surface elements
Volcano monitoring	Land surface elements
Conservation map plans	Land surface elements
Global ecosystem mapping	Land use classes
Migratory birds and management plans	Land use classes
Consumptive use	Land use classes
National watershed monitoring	Land use classes
Yield and water use estimates	Leaf Area Index (LAI)
Environmental impact assessment	Mineral type
Deposit modeling	Mineral type
Soil survey interpretation maps	Mineral type
Actuarial rate maps	Nonphotosynthetic vegetation
Crop Yield	Nonphotosynthetic vegetation
Crop residue monitoring	Nonphotosynthetic vegetation
Crop area	Nonphotosynthetic vegetation
Compliance monitoring investigations	Seasonally frozen ground
Crop residue monitoring	Soil disturbance
Global Land Cover 30-meters Dataset (GLC30m)	Surface reflectance
Yield and water use estimates	Surface reflectance
Actuarial rate maps	Surface water extent
Compliance monitoring investigations	Surface water extent
National crop forecast	Surface water extent
Landscape analysis and vegetation monitoring	Surface water extent
National watershed monitoring	Surface water extent
Resource inventories	Surface water extent
LANDFIRE existing vegetation	Top of atmosphere reflectance
National Landcover Dataset (NLCD)	Top of atmosphere reflectance
Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Tree cover canopy
National drought assessment	Vegetation condition
Phenology assessment	Vegetation condition
Actuarial rate maps	Vegetation condition
Actuarial rate maps	Vegetation condition
Compliance monitoring investigations	Vegetation condition
Determine condition of the vegetation on the rangelands	Vegetation condition
Consumptive use	Vegetation condition
Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Vegetation condition
Irrigation monitoring	Vegetation condition
Monitoring Trends in Burn Severity (MTBS)	Vegetation condition
Irrigated land dynamics	Vegetation condition
Forest disturbance queuing	Vegetation condition
Forest disturbance assessment	Vegetation condition
Global Land Cover 30-meter Dataset (GLC30m)	Vegetation cover
Compliance monitoring investigations	Vegetation cover
Multiresolution Land Characteristics (MRLC) tree canopy cover	Vegetation cover
Riparian vegetation mapping	Vegetation cover
National crop forecast	Vegetation disturbance
Compliance monitoring investigations	Vegetation disturbance
Emergency stabilization and rehabilitation plans	Vegetation disturbance
Compliance monitoring investigations	Vegetation species
Regional scale forest mapping	Vegetation species
National Cropland Data Layer (NCDL)	Vegetation species
Consumptive use	Vegetation species
Riparian vegetation mapping	Vegetation species
Sage Grouse conservation	Vegetation species
Multi-district mapping	Vegetation species
National insect and disease risk map	Vegetation species
Conservation map plans	Vegetation species
Volcano monitoring	Volcanic deposits

All threshold requirements satisfied by 15-meter resolution and any combination of VNIR and SWIR

→

Threshold requirements still met if shortwave infrared is not available

Key Product	Requirement
~~Consumptive use~~	~~Albedo~~
~~Irrigation monitoring~~	~~Albedo~~
~~Ecosystem carbon assessment~~	~~Biomass~~
~~Burned Area Emergency Response (BAER), Burned Area Reflectance Classification (BARC)~~	~~Burn severity~~
~~Monitoring Trends in Burn Severity (MTBS)~~	~~Burn severity~~
~~Emergency stabilization and rehabilitation plans~~	~~Burn severity~~
~~National land cover change assessment~~	~~Land cover~~
~~Disaster response~~	~~Land surface elements~~
~~Volcano monitoring~~	~~Land surface elements~~
~~Conservation map plans~~	~~Land surface elements~~
~~Global ecosystem mapping~~	~~Land use classes~~
~~Migratory birds and management plans~~	~~Land use classes~~
~~Consumptive use~~	~~Land use classes~~
~~National watershed monitoring~~	~~Land use classes~~
~~Yield and water use estimates~~	~~Leaf Area Index (LAI)~~
~~Environmental impact assessment~~	~~Mineral type~~
~~Deposit modeling~~	~~Mineral type~~
~~Soil survey interpretation maps~~	~~Mineral type~~
~~Actuarial rate maps~~	~~Nonphotosynthetic vegetation~~
~~Crop yield~~	~~Nonphotosynthetic vegetation~~
~~Crop residue monitoring~~	~~Nonphotosynthetic vegetation~~
~~Crop area~~	~~Nonphotosynthetic vegetation~~
Compliance monitoring investigations	Seasonally frozen ground
~~Crop residue monitoring~~	~~Soil disturbance~~
~~Global Land Cover 30-meter Dataset (GLC30m)~~	~~Surface reflectance~~
Yield and water use estimates	Surface reflectance
~~Actuarial rate maps~~	~~Surface water extent~~
~~Compliance monitoring investigations~~	~~Surface water extent~~
~~National crop forecast~~	~~Surface water extent~~
~~Landscape analysis and vegetation monitoring~~	~~Surface water extent~~
~~National watershed monitoring~~	~~Surface water extent~~
~~Resource inventories~~	~~Surface water extent~~
~~LANDFIRE existing vegetation~~	~~Top of atmosphere reflectance~~
~~National Landcover Dataset (NLCD)~~	~~Top of atmosphere reflectance~~
~~Rapid Assessment of Vegetation Condition after Wildfire (RAVG)~~	~~Tree cover canopy~~
National drought assessment	Vegetation condition
Phenology assessment	Vegetation condition
~~Actuarial rate maps~~	~~Vegetation condition~~
~~Actuarial rate maps~~	~~Vegetation condition~~
Compliance monitoring investigations	Vegetation condition
Determine condition of the vegetation on the rangelands	Vegetation condition
Consumptive use	Vegetation condition
~~Rapid Assessment of Vegetation Condition after Wildfire (RAVG)~~	~~Vegetation condition~~
Irrigation monitoring	Vegetation condition
~~Monitoring Trends in Burn Severity (MTBS)~~	~~Vegetation condition~~
~~Irrigated land dynamics~~	~~Vegetation condition~~
Forest disturbance queuing	Vegetation condition
Forest disturbance assessment	Vegetation condition
~~Global Land Cover 30-meter Dataset (GLC30m)~~	~~Vegetation cover~~
~~Compliance monitoring investigations~~	~~Vegetation cover~~
~~Multiresolution Land Characteristics (MRLC) tree canopy cover~~	~~Vegetation cover~~
Riparian vegetation mapping	Vegetation cover
~~National crop forecast~~	~~Vegetation disturbance~~
~~Compliance monitoring investigations~~	~~Vegetation disturbance~~
~~Emergency stabilization and rehabilitation plans~~	~~Vegetation disturbance~~
~~Compliance monitoring investigations~~	~~Vegetation species~~
~~Regional scale forest mapping~~	~~Vegetation species~~
~~National Cropland Data Layer (NCDL)~~	~~Vegetation species~~
~~Consumptive use~~	~~Vegetation species~~
~~Riparian vegetation mapping~~	~~Vegetation species~~
~~Sage Grouse conservation~~	~~Vegetation species~~
~~Multi-district mapping~~	~~Vegetation species~~
National insect and disease risk map	Vegetation species
Conservation map plans	Vegetation species
~~Volcano monitoring~~	~~Volcanic deposits~~

All threshold requirements satisfied by 15-meter resolution and any combination of VNIR and SWIR

Need for Concurrent Measurements

Subject matter experts often highlighted the need for concurrent measurements to support their key products and services:

☐ For many applications, concurrent water vapor and land surface temperature measurements are needed for calibration.

- For vegetation mapping, SMEs noted that higher accuracies are achieved when NIR and SWIR are observed together.
- Water vapor and aerosols need to be concurrently measured with multispectral data to improve calibration for minerals mapping activities, with accurate water vapor measurements being the most critical.
- For accurate surface energy calculations to support evapotranspiration (ET) estimation, thermal data need to be concurrently sampled with reflective bands so that temperature and albedo can be directly correlated.
- To correlate surface temperature correctly to vegetated and nonvegetated areas, SMEs identified the need to have TIR and SWIR collected coincidentally. Without it, leaf area index (LAI) cannot be spatially geolocated with temperature data.

Other Issues

The limited elicitation also provided information about other unique needs and (or) community concerns. A few examples include the following:

- Volcano monitoring would benefit from TIR and SWIR data at nighttime, particularly over high latitudes.
- Moderate Resolution Imaging Spectroradiometer (MODIS) data are widely used because of the twice daily refresh and a reasonable resolution and swath width. The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on the Suomi National Polar-orbiting Partnership (NPP) platform has been cited as the "follow-on" capability to MODIS; however, multiple SMEs express concern over the ability of VIIRS to offer similar capability and considerable uncertainty about how and from whom data will be available.
- Several SMEs indicated the need/desire for routine Landsat-derived products for surface reflectance, land surface temperature, surface water extent, and leaf area index.

Limitations

Because the set of user requirements described and analyzed in this summary report is the result of an evolving process and selective elicitations (as well as the pilot project itself), these results should not be considered a comprehensive or definitive statement of moderate resolution imaging requirements.

The nature of a process-oriented pilot project is necessarily limited in scope and a cycle of design-test-redesign-test until the desired process has been designed and tested successfully. The pilot project described in this summary report conforms to this description, recognizing that not all elements of the process were tested equally. Any shortfalls in testing and refining elements of the process will be addressed by the team before the final close-out of the pilot project.

The evolution of the elicitation and requirements development process throughout the pilot project resulted in collection of requirements information in slightly different ways from different SMEs. Although the project team does not believe the difference to be substantial, it should be noted as a limitation in the results.

To fit within the allotted time, only selected users of moderate resolution imagery in the USDA and DOI were elicited for requirements. Although the informal interview of state geospatial liaisons afforded some insight into state, local, tribal, academic, and private sector users, the large non-Federal user base of moderate resolution imagery has not been adequately covered in this pilot project.

Additionally because of time limitations, the requirements captured herein should be considered preliminary as in most cases there was time only for the initial requirements elicitation and a single

cursory review of the initial draft requirements by SMEs. Going forward, the requirements collected during the pilot project will need to be further developed to address the appropriateness of attributes to requirement level assigned, and to further remove them from ties to current (2013) capabilities and technologies.

Lastly, the requirements described above have not been validated to assure that they are the correct and complete requirements even for this limited set of elicitations. The experience of the project team in other agencies indicates that formal validation can be a multi-month to years-long process.

The NLIR pilot project created and tested a process to elicit and develop land imaging user requirements, focusing on moderate resolution imaging needs. The development of this process yielded a preliminary sample of moderate resolution imaging requirements that have been analyzed, with the preliminary results presented in the "User Requirements—A Preliminary Set" section. Additionally, the requirements captured during the pilot project are preliminary and need further development to enable their prioritization, verification, and validation.   Finally, because the set of user requirements is the result of an evolving process and selective elicitations, it should not be considered a comprehensive or definitive statement of moderate resolution imaging requirements.

Summary

This preliminary analysis of the draft user requirements gathered for the pilot project indicates close agreement with previous user requirement studies that focused on applications of moderate resolution imagery (Masek, J., Newman, T., Loveland, T., and Irons, J., unpub. data, 2012). This close agreement helps to substantiate the validity of the results. The pilot project data also reinforce existing user community knowledge that a reduction in revisit time, most notably from 16 to 8 days for Landsat, provides a substantial increase in their ability to meet land imaging frequency requirements.

Although not directly the focus of the requirements elicitation process, information collected during the pilot project also indicated user demand for higher level processed Landsat-type products; such as surface reflectance, land surface temperature, surface water extent, and leaf area index. The follow-on NLIR Project elicitation will be used to gauge the relative demand for these types of products.

This effort was highly successful in engaging land imaging users, capturing a preliminary set of user requirements, and establishing an enhanced elicitation process. This process, including lessons learned, will be used in follow-on NLIR elicitation efforts beginning in 2014.

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Appendix 1. Abbreviations

ALI	Advanced Land Imager
ARS	Agriculture Research Service, U.S. Department of Agriculture
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AWiFS	Advanced Wide Field Sensor
BLM	Bureau of Land Management, U.S. Department of the Interior
BOR	Bureau of Reclamation, U.S. Department of the Interior
CENRS	Committee on Environment, Natural Resources, and Sustainability
DMC	Disaster Monitoring Constellation
DOI	Department of the Interior
DOIRSWG	Department of the Interior Remote Sensing Working Group
EO	Earth Observation
EOA	Earth Observation Assessment
EORES	Earth Observation Requirements Evaluation System
ET	Evapotranspiration
FAQ	Frequently Asked Questions
FAS	Foreign Agricultural Service, U.S. Department of Agriculture
FWS	Fish and Wildlife Service, U.S. Department of the Interior
GCMD	Global Change Master Directory
GIS	Geographic Information System
KPS	Key Product or Service
LAI	Leaf Area Index
MSA	Mission Service Area
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautic and Space Administration
NASS	National Agricultural Statistics Service, U.S. Department of Agriculture
NDVI	Normalized Difference Vegetation Index
NGP	National Geospatial Program
NIR	Near Infrared
NLIR	National Land Imaging Requirements
NOAA	National Oceanic and Atmospheric Administration, U.S. Department of Commerce
NPP	National Polar-orbiting Partnership
NRCS	Natural Resources Conservation Service, U.S. Department of Agriculture
NSDI	National Spatial Data Infrastructure
PALMA™	Portfolio Analysis Machine (The MITRE Corporation)
PAN	Panchromatic
RMA	Risk Management Agency, U.S. Department of Agriculture
SBA	Societal Benefit Area
SMEs	Subject Matter Experts
SPOT	Satellite Pour l'Observation de la Terre
SO2	Sulfur Dioxide
SWIR	Short Wave Infrared
TIR	Thermal Infrared
UAS	Unmanned Aerial System
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UV	Ultraviolet
VIIRS	Visible Infrared Imaging Radiometer Suite
VNIR	Visible and Near-Infrared

Appendix 2. Survey of State Geospatial Liaisons

Geospatial Liaison Interviews—List of Interview Questions

PART 1: Use of Remote Sensing Data (General - All Types & Resolutions)

What are the primary uses or applications of <u>land remote sensing data</u> from any platform (satellites, aircraft, UAS, ground-based, etc.) in your state(s)?

Who are the primary users? State, local, or tribal government? Academia? The private sector? Do you have a general sense of the proportion of each?

Can you characterize the <u>level</u> of use for the primary applications? General categories could be:

    a. Remote sensing expert (independently exploits the spectral information in remotely-sensed data; may be developing new applications through novel use of data; well-versed in the details of its collection)

    b. GIS user (leverages GIS applications to overlay and analyze remotely-sensed data; typically versed in application of the data but not in the details of its collection)

    c. General user (primarily uses processed imagery, usually not integrated with analysis tools)

PART 2: Use of Remote Sensing Data (Specific to Moderate Resolution Imagery)

1. Do any of the remote sensing applications identified in PART 1 specifically use moderate resolution (5 to 120 meters) satellite imagery such as from Landsat? If so, which ones? (If not, skip to PART 3)

Generally, how well does the available moderate resolution imagery satisfy the needs or requirements for this type of data? (1 to 100: See rating scale below.)   The score may be an overall score, or a score for each user application. Please feel free to provide more details.

Performance / Satisfaction Scale		
100	Ideal	Meets all requirements and exceeds some
90	Fully Satisfied	Meets all requirements
80	Good	Meets all major requirements with minor limitations
70		
60	Fair	Meets most major requirements, with significant limitations
50		
40	Poor	Fails to meet many major requirements, but provides some value
30		
20	Very Poor	Fails to meet most major requirements, but provides minor value
10		
1	No Capability	Provides no value

Do you have a sense of any unmet needs that could potentially be addressed by moderate resolution satellite imagery, products, or services? Would changes to certain characteristics of the data (coverage, resolution, frequency, etc.) make it more useful in meeting these

needs?   Which of the characteristics, if improved, would have the biggest impact on the usefulness of the data?

For the users and activities of which you are aware, is there primarily a steady, persistent need for a core set of data, or is the need more project-oriented and variable?

Do you have a sense of how user needs may be changing? In the near future, mid-term, or longer term? If yes, please describe.

PART 3: Data Types/Formats and Software

1. What data types/formats and software applications are most common in the use of remotely sensed imagery in your state(s)?

Are there any known limitations regarding data and applications (e.g., ease of access, bandwidth limitations, formats, excessive pre-preprocessing steps, interoperability with other sources)? Do you have suggestions for improved data or software services?

PART 4: Further Assistance

1. Are you aware of any particular professional groups or associations who may be sources of additional information or may be interested in participating in a user-needs workshop or hosting a user-needs session in one of their conferences or similar activities?

The Federal Advisory Committee Act and the Paperwork Reduction Act limit the direct solicitation of information from non-Federal users.

   a. *Do you feel that you can adequately represent the users in your area of responsibility in additional*

       elicitations of the uses of and requirements for moderate resolution imagery?

   b. *Are you willing to participate in or facilitate a more in-depth assessment of uses of moderate resolution*

       imagery and requirements development?

Appendix 3. Societal Benefit Area Definitions

The societal benefit areas (SBAs) as defined in this report follow the definitions established in the National Strategy for Civil Earth Observations (Office of Science and Technology Policy, 2013). The plan lists 12 SBAs and the reference measurements that underpin them:

- ☐ **Agriculture and Forestry**—Supporting sustainable agriculture and forestry.
- ☐ **Biodiversity**—Understanding and conserving biodiversity.
- ☐ **Climate**—Understanding, assessing, predicting, mitigating, and adapting to climate variability and related global change.
- ☐ **Disasters**—Reducing loss of life, property, and ecosystem damage from natural and human-induced disasters.
- ☐ **Ecosystems (Terrestrial and Freshwater)** —Improving the management and protection of terrestrial and freshwater ecosystems.
- ☐ **Energy and Mineral Resources**—Improving the identification and management of energy and mineral resources.
- ☐ **Human Health**—Understanding environmental factors affecting human health and well-being.
- ☐ **Ocean and Coastal Resources and Ecosystems**—Understanding and protecting ocean, coastal, and Great Lakes populations and resources, including fisheries, aquaculture, and marine ecosystems.
- ☐ **Space Weather**—Understanding, assessing, predicting, and mitigating the effects of space weather on technological systems, including satellites, power grids, communications, and navigation.
- ☐ **Transportation**—Improving the safety and efficiency of all modes of transportation, including air, highway, railway, and marine.
- ☐ **Water Resources**—Improving water resource management through better understanding and monitoring of the water cycle.
- ☐ **Weather**—Improving weather information, forecasting, and warning.
- ☐ **Reference Measurements**—Improving reference measurements—the underpinnings of all the SBAs—such as geodesy, bathymetry, topography, geolocation, and the fundamental measurement systems and standards supporting them.

These SBAs are interconnected and include scientific research, economic activities, and environmental and social domains. Multiple SBAs share observational requirements, and societal benefits accrue from Earth observations that inform scientific research, policy, and decisionmaking. Earth observations also support critical government functions, such as the continuity of national government and the protection of life and property.

Appendix 4. Preliminary User Requirements Summary Information

National Land Imaging Requirements Pilot Project

Preliminary Threshold and Breakthrough User Requirements Summary - Resolution and Revisit

[m, meters; dy, days; blue denotes threshold level; red denotes breakthrough level]			Resolution							Revisit			
Mission Service Area (MSA)	**Supported Key Product or Service (KPS)**	**Requirement**	< 5 m	5 m	≤ 15 m	≤ 30 m	≤ 60 m	≤ 100 m	> 100 m	< 2 dy	≤ 4 dy	≤ 8 dy	≤ 16 dy
Water management and delivery	Consumptive use	Albedo				R		B				B	
Land change products	Irrigation monitoring	Albedo				B						B	
Climate and land use change / land carbon research	Ecosystem carbon assessment	Biomass				B							
Assessment of forest affected by abiotic agents	Burned Area Emergency Response (BAER), Burned Area Reflectance Classification (BARC)	Burn severity				B					R		
Assessment of forest affected by abiotic agents	Monitoring Trends in Burn Severity (MTBS)	Burn severity				B							
Inventory and monitoring	Emergency stabilization and rehabilitation plans	Burn severity				B						B	
Climate and land use change / land carbon research	Vegetation Change Tracker (VCT)	Cloud presence				R	B						B
Volcanoes	Volcano monitoring	Dust / ash / smoke					R	B					
Volcanoes	Volcano assessment	Dust / ash / smoke					R	B					
Volcanoes	Volcano research	Eruption dynamics / lahars and debris flow			B								B
Volcanoes	Volcano assessment	Eruption dynamics / pyroclastic flow		R		B				B			
Volcanoes	Volcano assessment	Eruption dynamics / lava speed / flow		R		B							
Climate and land use change / land carbon research	Vegetation Change Tracker (VCT)	Land cover				B							B
Climate and land use change / land change products	National land cover change assessment	Land cover				B						R	B
Regulating coal mines	Contemporaneous reclamation monitoring	Land surface elements			B								B
Regulating coal mines	Monitoring long-term restoration of mined areas	Land surface elements			B								B
Soil and water conservation	Disaster response	Land surface elements				B				R	B		
Soil and water conservation	Disaster response	Land surface elements	B									B	
Volcanoes	Volcano monitoring	Land surface elements		R	B						B		
Soil and water conservation	Conservation map plans	Land surface elements		R		B							B
Global crop forecasting	Crop yield	Land surface temperature						B				B	

[m, meters; dy, days; blue denotes threshold level; red denotes breakthrough level]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Resolution							Revisit			
			< 5 m	5 m	≤ 15 m	≤ 30 m	≤ 60 m	≤ 100 m	> 100 m	< 2 dy	≤ 4 dy	≤ 8 dy	≤ 16 dy
Land change products	Irrigation monitoring	Land surface temperature				R		B			R	B	
National crop forecasting	National crop forecast	Land surface temperature							B	R	B		
National crop forecasting	Yield and water use estimates	Land surface temperature					R	B				R	B
Water management and delivery	Consumptive use	Land surface temperature						B					B
Water management and delivery	Riparian vegetation mapping	Land surface temperature				R	B						B
Climate and land use change / land carbon research	Ecosystem carbon assessment	Land use classes				B						B	
Global crop forecasting	Crop area	Land use classes		B									B
Global crop forecasting	Crop area	Land use classes				R		B					B
Climate and land use change / ecosystem services	Global ecosystem mapping	Land use classes				R		B					B
Strategic habitat conservation / inventory and monitoring	Migratory birds and management plans	Land use classes			R	B						R	B
Water management and delivery	Consumptive use	Land use classes				B							B
Water science / hydrologic research and development	National watershed monitoring	Land use classes				B						R	B
Volcanoes	Volcano monitoring	Lava flow temperature		R			B			B			
National crop forecasting	Yield and water use estimates	Leaf Area Index (LAI)				B					R		B
Mineral resources	Minerals assessment	Mineral type			B								B
Mineral resources	Minerals assessment	Mineral type		R									B
Mineral resources	Environmental impact assessment	Mineral type		R									B
Mineral resources	Deposit modeling	Mineral type		R	B								B
Soil and water conservation	Soil survey interpretation maps	Mineral type				B							B
Compliance monitoring	Actuarial rate maps	Nonphotosynthetic vegetation				B						B	
Global crop forecasting	Crop yield	Nonphotosynthetic vegetation				B							B
Soil and water conservation	Crop residue monitoring	Nonphotosynthetic vegetation				B						B	
Soil and water conservation	Crop residue monitoring	Nonphotosynthetic vegetation				B						B	
Climate and land use change / land carbon research	Ecosystem carbon assessment	Salinity				B							B

Preliminary Threshold and Breakthrough User Requirements Summary - Resolution and Revisit--Cont.

[m, meters; dy, days; blue denotes threshold level; red denotes breakthrough level]			Resolution							Revisit			
Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	< 5 m	5 m	≤ 15 m	≤ 30 m	≤ 60 m	≤ 100 m	> 100 m	< 2 dy	≤ 4 dy	≤ 8 dy	≤ 16 dy
Compliance monitoring	Compliance monitoring investigations	Seasonally frozen ground				R					R		
Climate and land use change / land carbon research	Ecosystem carbon assessment	Soil classification				B						B	
Conservation of forest biological diversity	Digital soil mapping	Soil classification				B							B
Soil and water conservation	Crop residue monitoring	Soil disturbance				B				B	B		
Compliance monitoring	Compliance monitoring investigations	Soil moisture / water content			R	B					B		
Global crop forecasting	Crop yield	Soil moisture / water content					B				B		
Land management	Local drought assessments	Soil moisture / water content			R	B					B		
Volcanoes	Volcano monitoring	Sulfur dioxide					R		B	B			
Volcanoes	Volcano assessment	Sulfur dioxide					R		B				
Climate and land use change / land change products	Global Land Cover 30-meter Dataset (GLC30m)	Surface reflectance				B					R	B	
National crop forecasting	Yield and water use estimates	Surface reflectance				B						R	B
Global crop forecasting	Crop area	Surface water extent							B				
Volcanoes	Volcano research	Surface water extent			B								B
Strategic habitat conservation / inventory and monitoring	Migratory birds and management plans	Surface water extent	R	B							B		
Compliance monitoring	Actuarial rate maps	Surface water extent			R	B					B		
Compliance monitoring	Compliance monitoring investigations	Surface water extent			R	B					B		
National crop forecasting	National crop forecast	Surface water extent				B							
Strategic habitat conservation / inventory and monitoring	Landscape analysis and vegetation monitoring	Surface water extent			R	B						R	B
Water science / hydrologic research and development	National watershed monitoring	Surface water extent				B						B	
Soil and water conservation	Resource inventories	Surface water extent				B							
Intermediate products	LANDFIRE existing vegetation	Top of atmosphere reflectance				B						B	
Intermediate products	National Landcover Dataset (NLCD)	Top of atmosphere reflectance				B							B
Assessment of forest affected by abiotic agents	Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Tree cover canopy				B						B	
Global crop forecasting	Crop yield	Vegetation condition				R			B	B			

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Resolution							Revisit			
[m, meters; dy, days; blue denotes threshold level; red denotes breakthrough level]			< 5 m	≤ 5 m	≤ 15 m	≤ 30 m	≤ 60 m	≤ 100 m	> 100 m	< 2 dy	≤ 4 dy	≤ 8 dy	≤ 16 dy
Global crop forecasting	Crop yield	Vegetation condition		blue						blue			
Global crop forecasting	Rapid response	Vegetation condition							blue	blue			
Land management	Local drought assessments	Vegetation condition			red	blue						blue	
National crop forecasting	National crop forecast	Vegetation condition							blue	red			
Climate and land use change / land change products	National drought assessment	Vegetation condition							blue		blue		
Climate and land use change / land change products	Phenology assessment	Vegetation condition							blue		blue		
Compliance monitoring	Actuarial rate maps	Vegetation condition											blue
Compliance monitoring	Actuarial rate maps	Vegetation condition				blue					red		
Compliance monitoring	Compliance monitoring investigations	Vegetation condition				blue					blue		
Compliance monitoring	Determine condition of the vegetation on the rangelands	Vegetation condition							blue		blue		
Water management and delivery	Consumptive use	Vegetation condition				red			blue		red		blue
Assessment of forest affected by abiotic agents	Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Vegetation condition				blue					blue		
Land change products	Irrigation monitoring	Vegetation condition				blue					red		
Maintenance of ecosystem health and safety	Forest disturbance assessment	Vegetation condition	blue								blue		
Assessment of forest affected by abiotic agents	Monitoring Trends in Burn Severity (MTBS)	Vegetation condition				blue							blue
Climate and land use change / land change products	Irrigated land dynamics	Vegetation condition				red			blue	red	blue		
Maintenance of ecosystem health and safety	Forest disturbance queing	Vegetation condition							blue				
Maintenance of ecosystem health and safety	Forest disturbance assessment	Vegetation condition				blue					red	blue	
Climate and land use change / land change products	Global Land Cover 30-meter Dataset (GLC30m)	Vegetation cover				blue						blue	
Compliance monitoring	Compliance monitoring investigations	Vegetation cover				blue						blue	
Conservation of forest biological diversity	Multiresolution land characteristics tree canopy cover	Vegetation cover				blue						red	blue
Water management and delivery	Riparian vegetation mapping	Vegetation cover				blue						blue	
Mineral resources	Environmental impact assessment	Vegetation cover		blue									blue
Climate and land use change / land carbon research	Vegetation Change Tracker (VCT)	Vegetation disturbance				blue							blue

Preliminary Threshold and Breakthrough User Requirements Summary - Resolution and Revisit--Cont.

[m, meters; dy, days; blue denotes threshold level; red denotes breakthrough level]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Resolution < 5 m	5 m	≤ 15 m	≤ 30 m	≤ 60 m	≤ 100 m	> 100 m	Revisit < 2 dy	≤ 4 dy	≤ 8 dy	≤ 16 dy
National crop forecasting	National crop forecast	Vegetation disturbance				B				B			
Compliance monitoring	Compliance monitoring investigations	Vegetation disturbance			R	B					B		
Inventory and monitoring	Emergency stabilization and rehabilitation plans	Vegetation disturbance		R		B						B	
Conservation of forest biological diversity	Forest resource mapping for inventory and monitoring	Vegetation species				B							B
Global crop forecasting	Crop area	Vegetation species				B						B	
National crop forecasting	National crop forecast	Vegetation species			R	B					R	B	
Compliance monitoring	Compliance monitoring investigations	Vegetation species				B					B		
Conservation of forest biological diversity	Regional scale forest mapping	Vegetation species				B						R	B
Intermediate products	National Cropland Data Layer (NCDL)	Vegetation species				B					B		
National crop forecasting	National Agricultural Statistics Service area sampling frame	Vegetation species	B										B
Water management and delivery	Consumptive use	Vegetation species	R			B							B
Water management and delivery	Riparian vegetation mapping	Vegetation species	R		B								B
Inventory and monitoring	Sage Grouse conservation	Vegetation species				B							B
Land management	Detailed vegetation classification	Vegetation species		B									B
Land management	Multi-district mapping	Vegetation species				B							B
Maintenance of ecosystem health and safety	National Insect and Disease Risk Map	Vegetation species			R	B							B
Soil and water conservation	Conservation map plans	Vegetation species		R		B							B
Mineral resources	Environmental impact assessment	Vegetation type		B									B
Volcanoes	Hazards communication	Volcanic activity	R	B						B			
Volcanoes	Volcano monitoring	Volcanic deposits			R	B							
Strategic habitat conservation / inventory and monitoring	Landscape analysis and vegetation monitoring	Wetland classification		B							B		
Global crop forecasting	Rapid response	Wildfires							B	B			

National Land Imaging Requirements Pilot Project
Preliminary Threshold and Breakthrough User Requirements Summary - Spectral Bands

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic; UV, ultraviolet; blue cell denotes threshold level; red cell denotes breakthrough level; purple cell denotes SWIR bands currently used but additional bands needed]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Blue	Green	Red	NIR	SWIR	TIR	PAN	UV	Yellow	Red Edge
Water management and delivery	Consumptive use	Albedo	■	■	■	■	■					
Land change products	Irrigation monitoring	Albedo	■	■	■	■	■					
Climate and land use change / land carbon research	Ecosystem carbon assessment	Biomass	■	■	■	■	■					
Assessment of forest affected by abiotic agents	Burned Area Emergency Response (BAER), Burned Area Reflectance Classification (BARC)	Burn severity				■	■					
Assessment of forest affected by abiotic agents	Monitoring Trends in Burn Severity (MTBS)	Burn severity				■	■					
Inventory and monitoring	Emergency stabilization and rehabilitation plans	Burn severity				■	■					
Climate and land use change / land carbon research	Vegetation Change Tracker (VCT)	Cloud presence						■				
Volcanoes	Volcano monitoring	Dust / ash / smoke						■		■		
Volcanoes	Volcano assessment	Dust / ash / smoke						■		■		
Volcanoes	Volcano research	Eruption dynamics / lahars and debris flow	■	■	■	■						
Volcanoes	Volcano assessment	Eruption dynamics / pyroclastic flow					■	■				
Volcanoes	Volcano assessment	Eruption dynamics / lava speed / flow					■	■				
Climate and land use change / land carbon research	Vegetation Change Tracker (VCT)	Land cover	■	■	■	■	■					
Climate and land use change / land change products	National Land Cover Change Assessment	Land cover	■	■	■	■	■		🟥			
Regulating coal mines	Contemporaneous reclamation monitoring	Land surface elements	■	■	■	■	■		■			
Regulating coal mines	Monitoring long-term restoration of mined areas	Land surface elements	■	■	■	■	■		■			
Soil and water conservation	Disaster response	Land surface elements	■	■	■	■	■		■			
Soil and water conservation	Disaster response	Land surface elements	■	■	■	■	■		■			
Volcanoes	Volcano monitoring	Land surface elements							■			
Soil and water conservation	Conservation map plans	Land surface elements	■	■		■						
Global crop forecasting	Crop yield	Land surface temperature						■				
Land change products	Irrigation monitoring	Land surface temperature						■				

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Preliminary Threshold and Breakthrough User Requirements Summary - Spectral Bands--Cont.

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic; UV, ultraviolet; blue cell denotes threshold level; red cell denotes breakthrough level; purple cell denotes SWIR bands currently used but additional bands needed]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement		Blue	Green	Red	NIR	SWIR	TIR	PAN	UV	Yellow	Red Edge
National crop forecasting	National crop forecast	Land surface temperature							■				
National crop forecasting	Yield and water use estimates	Land surface temperature							■				
Water management and delivery	Consumptive use	Land surface temperature							■				
Water management and delivery	Riparian vegetation mapping	Land surface temperature							■				
Climate and land use change / land carbon research	Ecosystem carbon assessment	Land use classes		■	■	■	■	■	■				
Global crop forecasting	Crop area	Land use classes		■	■	■	■	■	■				
Global crop forecasting	Crop area	Land use classes		■	■	■	■	■	■				
Climate and land use change / ecosystem services	Global ecosystem mapping	Land use classes		■	■	■	■	■					
Strategic habitat conservation / inventory and monitoring	Migratory birds and management plans	Land use classes		■	■	■	■	■					
Water management and delivery	Consumptive use	Land use classes		■	■	■	■	■					
Water science / hydrologic research and development	National watershed monitoring	Land use classes		■	■	■	■	■					
Volcanoes	Volcano monitoring	Lava flow temperature						■	■				
National crop forecasting	Yield and water use estimates	Leaf Area Index (LAI)		■	■	■	■	■					
Mineral resources	Minerals assessment	Mineral type		■	■	■	■	■	■				
Mineral resources	Minerals assessment	Mineral type		■	■	■	■	■	■	▥		▥	▥
Mineral resources	Environmental impact assessment	Mineral type		■	■	■	■	■	▥	■			▥
Mineral resources	Deposit modeling	Mineral type		■	■	■	■	■	▥			▥	
Soil and water conservation	Soil survey interpretation maps	Mineral type		■	■	■	■	■					
Compliance monitoring	Actuarial rate maps	Nonphotosynthetic vegetation						■					
Global crop forecasting	Crop yield	Nonphotosynthetic vegetation						▦	▥				
Soil and water conservation	Crop residue monitoring	Nonphotosynthetic vegetation						▦					
Soil and water conservation	Crop residue monitoring	Nonphotosynthetic vegetation						▦					
Climate and land use change / land carbon research	Ecosystem Carbon Assessment	Salinity		■	■	■	■	■	■				

(■ = threshold/blue cell; ▥ = breakthrough/red cell; ▦ = purple cell, SWIR band currently used but additional bands needed)

Preliminary Threshold and Breakthrough User Requirements Summary - Spectral Bands--Cont.

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic; UV, ultraviolet; blue cell denotes threshold level; red cell denotes breakthrough level; purple cell denotes SWIR bands currently used but additional bands needed]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Blue	Green	Red	NIR	SWIR	TIR	PAN	UV	Yellow	Red Edge
Compliance monitoring	Compliance Monitoring Investigations	Seasonally frozen ground						■(red)				
Climate and land use change / land carbon research	Ecosystem carbon assessment	Soil classification	■	■	■	■	■	■				
Conservation of forest biological diversity	Digital soil mapping	Soil classification	■	■	■	■	■	■				
Soil and water conservation	Crop residue monitoring	Soil disturbance					■(purple)					
Compliance monitoring	Compliance monitoring investigations	Soil moisture / water content						■				
Global crop forecasting	Crop yield	Soil moisture / water content						■				
Land management	Local drought assessments	Soil moisture / water content					■					
Volcanoes	Volcano monitoring	Sulfur dioxide								■		
Volcanoes	Volcano assessment	Sulfur dioxide								■		
Climate and land use change / land change products	Global Land Cover 30-meter Dataset (GLC30m)	Surface reflectance			■	■	■					
National crop forecasting	Yield and water use estimates	Surface reflectance	■	■								
Global crop forecasting	Crop area	Surface water extent						■				
Volcanoes	Volcano research	Surface water extent	■	■	■							
Strategic habitat conservation / inventory and monitoring	Migratory birds and management plans	Surface water extent								■		
Compliance monitoring	Actuarial rate maps	Surface water extent		■		■	■					
Compliance monitoring	Compliance monitoring investigations	Surface water extent		■		■	■					
National crop forecasting	National crop forecast	Surface water extent	■	■	■							
Strategic habitat conservation / inventory and monitoring	Landscape analysis and vegetation monitoring	Surface water extent	■	■	■	■	■					
Water science / hydrologic research and development	National watershed monitoring	Surface water extent	■	■	■	■	■					
Soil and water conservation	Resource inventories	Surface water extent		■		■	■					
Intermediate products	LANDFIRE existing vegetation	Top of atmosphere reflectance	■	■	■	■	■					

Preliminary Threshold and Breakthrough User Requirements Summary - Spectral Bands--Cont.

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic; UV, ultraviolet; blue cell denotes threshold level; red cell denotes breakthrough level; purple cell denotes SWIR bands currently used but additional bands needed]

Cell legend: T = threshold (blue), B = breakthrough (red)

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Blue	Green	Red	NIR	SWIR	TIR	PAN	UV	Yellow	Red Edge
Intermediate products	National Landcover Dataset (NLCD)	Top of atmosphere reflectance	T	T	T	T	T					
Assessment of forest affected by abiotic agents	Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Tree cover canopy	T	T	T	T	T					
Global crop forecasting	Crop yield	Vegetation condition			T	T	T	T				
Global crop forecasting	Crop yield	Vegetation condition	T		T	T	T					
Global crop forecasting	Rapid response	Vegetation condition			T	T	T	T				
Land management	Local drought assessments	Vegetation condition					T	T				
National crop forecasting	National crop forecast	Vegetation condition			T	T	T					
Climate and land use change / land change products	National Drought Assessment	Vegetation condition	T									
Climate and land use change / land change products	Phenology assessment	Vegetation condition			T	T						
Compliance monitoring	Actuarial rate maps	Vegetation condition			T	T	T					
Compliance monitoring	Actuarial rate maps	Vegetation condition			T	T						
Compliance monitoring	Compliance monitoring investigations	Vegetation condition										B
Compliance monitoring	Determine condition of the vegetation on the rangelands	Vegetation condition										B
Water management and delivery	Consumptive use	Vegetation condition			T	T						
Assessment of forest affected by abiotic agents	Rapid Assessment of Vegetation Condition after Wildfire (RAVG)	Vegetation condition	T	T	T	T	T		T			
Land change products	Irrigation monitoring	Vegetation condition			T	T	T		T			
Maintenance of ecosystem health and safety	Forest disturbance assessment	Vegetation condition	T	T	T				T			B
Assessment of forest affected by abiotic agents	Monitoring Trends in Burn Severity (MTBS)	Vegetation condition			T	T						
Climate and land use change / land change products	Irrigated land dynamics	Vegetation condition	T	T	T	T	T	B				
Maintenance of ecosystem health and safety	Forest disturbance queuing	Vegetation condition			T	T	T		T			
Maintenance of ecosystem health and safety	Forest disturbance assessment	Vegetation condition									B	
Climate and land use change / land change products	Global Land Cover 30-meter Dataset (GLC30m)	Vegetation cover	T	T	T	T	T		T			
Compliance monitoring	Compliance monitoring investigations	Vegetation cover	T	T	T	T	T					

Preliminary Threshold and Breakthrough User Requirements Summary - Spectral Bands--Cont.

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic; UV, ultraviolet; blue cell denotes threshold level; red cell denotes breakthrough level; purple cell denotes SWIR bands currently used but additional bands needed]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Blue	Green	Red	NIR	SWIR	TIR	PAN	UV	Yellow	Red Edge
Conservation of forest biological diversity	Multiresolution land characteristics tree canopy cover	Vegetation cover	X	X	X	X	X					
Water management and delivery	Riparian vegetation mapping	Vegetation cover	X	X	X	X						
Mineral resources	Environmental impact assessment	Vegetation cover	X	X	X	X	X		X			
Climate and land use change / land carbon research	Vegetation Change Tracker (VCT)	Vegetation disturbance	X	X	X	X	X		X			
National crop forecasting	National crop forecast	Vegetation disturbance	X	X	X	X	X		X			
Compliance monitoring	Compliance monitoring investigations	Vegetation disturbance	X	X	X	X						
Inventory and monitoring	Emergency stabilization and rehabilitation plans	Vegetation disturbance					X					
Conservation of forest biological diversity	Forest resource mapping for inventory and monitoring	Vegetation species	X	X	X	X	X		X			
Global crop forecasting	Crop area	Vegetation species	X	X	X	X	X					
National crop forecasting	National crop forecast	Vegetation species	X	X	X	X	X					R
Compliance monitoring	Compliance monitoring investigations	Vegetation species	X	X	X	X	X					R
Conservation of forest biological diversity	Regional scale forest mapping	Vegetation species	X	X	X	X	X					
Intermediate Products	National Cropland Data Layer (NCDL)	Vegetation species	X	X	X	X	X					
National crop forecasting	National Agricultural Statistics Service area sampling frame	Vegetation species	X	X	X	X						
Water management and delivery	Consumptive use	Vegetation species	X	X	X	X	X					
Water management and delivery	Riparian vegetation mapping	Vegetation species	X	X	X	X	X					
Inventory and monitoring	Sage Grouse conservation	Vegetation species	X	X	X	X	X					
Land management	Detailed vegetation classification	Vegetation species	X	X	X	X	X					
Land management	Multi-district mapping	Vegetation species	X	X	X	X	X					
Maintenance of ecosystem health and safety	National Insect and Disease Risk Map	Vegetation species	X	X	X	X						
Soil and water conservation	Conservation map plans	Vegetation species	X	X		X						
Mineral resources	Environmental impact assessment	Vegetation type	X	X	X	X	X	X	X			

Preliminary Threshold and Breakthrough User Requirements Summary - Spectral Bands--Cont.

[NIR, near infrared; SWIR, shortwave infrared; TIR, thermal infrared; PAN, panchromatic; UV, ultraviolet; blue cell denotes threshold level; red cell denotes breakthrough level; purple cell denotes SWIR bands currently used but additional bands needed]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Blue	Green	Red	NIR	SWIR	TIR	PAN	UV	Yellow	Red Edge
Volcanoes	Hazards communication	Volcanic activity							■			
Volcanoes	Volcano monitoring	Volcanic deposits	■	■	■	■	■					
Strategic habitat conservation / inventory and monitoring	Landscape analysis and vegetation monitoring	Wetland classification				■						
Global crop forecasting	Rapid response	Wildfires						■				

National Land Imaging Requirements Pilot Project

Preliminary Target User Requirements Summary - Resolution and Revisit

[Green denotes target requirement]

Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	< 5 meters	5 meters	≤ 15 meters	≤ 30 meters	≤ 60 meters	≤ 100 meters	> 100 meters	< 2 days	< 4 days	< 8 days	≤ 16 days
Mineral resources	Minerals assessment	Mineral type				■							■
Mineral resources	Deposit modeling	Mineral type				■							■
National crop forecasting	National crop forecast	Vegetation species			■					■			
Water management and delivery	Riparian vegetation mapping	Vegetation species	■										■
Water management and delivery	Riparian vegetation mapping	Vegetation species	■										■
National crop forecasting	Yield and water use estimates	Land surface temperature				■						■	
National crop forecasting	Yield and water use estimates	Surface reflectance				■						■	
Climate and land use change / ecosystem services	Global ecosystem mapping	Land use classes				■							■
Conservation of forest biological diversity	Regional scale forest mapping	Vegetation species				■						■	
Water science / hydrologic research and development	National watershed monitoring	Land use classes				■					■		
Maintenance of ecosystem health and safety	Forest disturbance assessment	Vegetation condition	■									■	
Maintenance of ecosystem health and safety	Effectiveness of mitigation	Vegetation condition	■									■	
Land change products	Irrigation monitoring	Vegetation condition									■		
Volcanoes	Volcano monitoring	Volcanic deposits		■									■
Volcanoes	Volcano monitoring	Land surface elements	■							■			

National Land Imaging Requirements Pilot Project

Preliminary Target User Requirements Summary - Spectral Bands

[Green denotes target requirement]			Spectral Bands									
Mission Service Area (MSA)	Supported Key Product or Service (KPS)	Requirement	Blue	Green	Red	Near Infrared	Shortwave Infrared	Thermal Infrared	Panchromatic	Ultraviolet	Yellow	Red Edge
Mineral resources	Minerals assessment	Mineral type	✓	✓	✓	✓	✓					
Mineral resources	Deposit modeling	Mineral type	✓	✓	✓	✓	✓					✓
National crop forecasting	National crop forecast	Vegetation species	✓	✓	✓	✓	✓	✓				
Water management and delivery	Riparian vegetation mapping	Vegetation species	✓	✓	✓	✓	✓					
Water management and delivery	Riparian vegetation mapping	Vegetation species	✓	✓	✓	✓	✓					
National crop forecasting	Yield and water use estimates	Land surface temperature						✓				
National crop forecasting	Yield and water use estimates	Surface reflectance	✓	✓	✓	✓	✓					
Climate and land use change / ecosystem services	Global ecosystem mapping	Land use classes	✓	✓	✓	✓	✓					
Conservation of forest biological diversity	Regional scale forest mapping	Vegetation species	✓	✓	✓	✓	✓					
Water science / hydrologic research and development	National watershed monitoring	Land use classes	✓	✓	✓	✓	✓					
Maintenance of ecosystem health and safety	Forest disturbance assessment	Vegetation condition	✓	✓	✓				✓			
Maintenance of ecosystem health and safety	Effectiveness of mitigation	Vegetation condition				✓	✓					
Land change products	Irrigation monitoring	Vegetation condition			✓	✓			✓			
Volcanoes	Volcano monitoring	Volcanic deposits	✓	✓	✓	✓	✓					
Volcanoes	Volcano monitoring	Land surface elements							✓			