

The background is a collage of four images: top-left shows a tablet with a heart and 'SICKNESS RATE' graph; top-right shows a rack of test tubes; bottom-left shows a field of crops; bottom-right shows hands being washed under a faucet. A logo consisting of four colored squares (blue, purple, grey, orange) is positioned to the left of the title.

# SBG User Needs and Valuation Study

Final Report, September 2020  
NASA HQ Contract No. 1641916

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**This final report has been approved by the RTI Innovation Advisors for public dissemination.**

**Please Note:** This report is a good faith effort by RTI to accurately represent information available via secondary and primary sources at the time of the information capture.

# Abbreviations

<b>ADS</b>	Aerial Detection Survey	<b>NIFC</b>	National Interagency Fire Center
<b>ASTER</b>	Advanced Spaceborne Thermal Emission and Reflection Radiometer	<b>NIH</b>	US National Institutes of Health
<b>AVIRIS</b>	Airborne Visible Infrared Imaging Spectrometer	<b>NIR</b>	near-infrared
<b>CDC</b>	US Centers for Disease Control and Prevention	<b>NPK</b>	nitrogen, phosphorus, and potassium
<b>CDOM</b>	colored dissolved organic matter	<b>POM</b>	particulate organic matter
<b>DO</b>	Designated Observable	<b>RFF</b>	Resources for the Future
<b>DS</b>	Decadal Survey	<b>RPRP</b>	Right Place, Right Practice
<b>DVF</b>	desirability, viability, and feasibility framework	<b>RS</b>	remote sensing
<b>EO</b>	Earth observation	<b>SATM</b>	Science Applications Traceability Matrix
<b>EPA</b>	US Environmental Protection Agency	<b>SBG</b>	Surface Biology and Geology
<b>ET</b>	evapotranspiration	<b>SNRs</b>	signal-to-noise ratios
<b>FEWS-NET</b>	Famine Early Warning System	<b>SWIR</b>	shortwave infrared
<b>GRSC</b>	Geological Remote Sensing Group	<b>T2P</b>	Technology Transfer Program
<b>HAB</b>	harmful algal bloom	<b>TIR</b>	thermal infrared
<b>HIS</b>	hyperspectral imaging spectroscopy	<b>USDA</b>	US Department of Agriculture
<b>Landsat</b>	Earth-observing satellite missions jointly run by NASA and the US Geological Survey	<b>VALUABLES</b>	Consortium for the Valuation of Application Benefits Linked with Earth Science
<b>MODIS</b>	Moderate Resolution Imaging Spectroradiometer	<b>VASP</b>	value-added service provider
<b>MRV</b>	monitoring, reporting, and verification	<b>VIIRS</b>	visible infrared imaging radiometer suite
<b>NDIS</b>	National Drought Information System	<b>VIS-NIR</b>	visible to near-infrared
<b>NDVI</b>	normalized difference vegetation index	<b>VRT</b>	variable-rate application technology
<b>NGO</b>	nongovernmental organization	<b>VSWIR</b>	visible to shortwave infrared



# Executive Summary

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# Executive Summary—Background

The National Academies 2018 Decadal Survey (DS) outlines the science and Designated Observable (DO) missions that NASA will explore from 2017 to 2027. NASA is proposing to meet this directive with four DO missions, one of which is a global imaging spectroscopy Surface Biology and Geology (SBG) DO mission and investigation. The prospective SBG mission will advance future science on the global atmosphere, cryosphere, and terrestrial and aquatic ecosystems. SBG will also support a broad range of Earth observation (EO) applications and decision-making in water resources, agriculture, health, and disaster management. SBG represents a unique EO platform combining hyperspectral visible to short wave infrared (VSWIR) and thermal infrared (TIR) imaging spectroscopy capabilities for unmatched global coverage and coincident spectral resolution. SBG could provide an unprecedented volume of global spectral imaging data with the potential to transform remote sensing practices.

Beyond designing SBG architectures to meet the science themes noted, the DS also calls on NASA to engage not just the scientific research user community but also private and public users to enable SBG to potentially address a broader set of applications supporting societal and industry objectives. To this end, the SBG Applications team worked in collaboration with RTI Innovation Advisors (RTI) to undertake this unique SBG *User Needs and Valuation* research study. RTI and the SBG Applications team began work on the study in January 2020 when the full SBG architecture team was in Phase 2. The methods, collaboration, and duration of the subject study were designed to augment and coincide with SBG architecture down-selection analyses and SBG community assessment reporting efforts.

This final research study report reflects the complete set of insights, including early and essential directional support from the SBG Application team leads, and the findings of extensive survey and primary research with end users. From many potential end use applications the SBG team guided a down selection, see page 8, to provide focus for this study. The key user needs and valuation findings along with RTI's observations are presented for these four primary SBG application areas: fire ecology and risk, agriculture and water resources, algal blooms and water quality, and mineral resources, with additional insights on value-added service providers (VASPs). Lastly, the report presents RTI's recommendations in four thematic areas: coordination, communication, competency, and collaboration.

# Executive Summary—User-Centered Design

RTI used a user-centered design framework to define the primary work streams for the study. By focusing on key user-centered variables—**Desirability**: assessing the needs of target EO end users and their perceptions of SBG capabilities; **Viability**: socioeconomic valuation; **Feasibility**—RTI was able to augment the NASA SBG team’s considerations related to SBG practical applications and related architectures. Part of the intent of this user-centered research was to serve as a pilot effort for NASA to consider best practices and methods related to engaging nontraditional private- and public-sector users, assessing their unique needs, and providing qualitative and quantitative valuations of the key benefits NASA’s EO capabilities might bring to these targeted users.

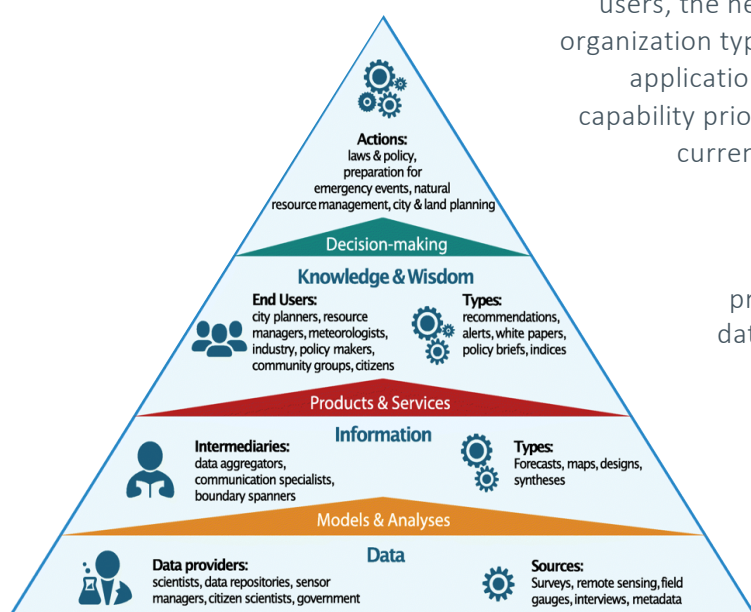
## User-Centered Design Framework

USER-CENTERED DESIGN VARIABLES	<b>D</b>	DESIREABILITY	<ul style="list-style-type: none"><li>• Users, user archetypes</li><li>• Use cases, application archetypes</li><li>• Users’ jobs to be done and needs</li><li>• Users’ perception of benefits</li></ul>
	<b>V</b>	VIABILITY	<ul style="list-style-type: none"><li>• Value framework</li><li>• Value drivers—social, health, economic, environmental</li><li>• Value measures</li></ul>
	<b>F</b>	FEASIBILITY	<ul style="list-style-type: none"><li>• Performance, operational capabilities, partnerships</li></ul>

RTI also employed the “jobs to be done” methodology of user-centered design by considering the “jobs” that a select set of nontraditional users are trying to accomplish with EOs. These “jobs,” or activities or use cases, are in effect potential opportunities for SBG. In these situations, SBG might provide a tangible benefit to users trying to accomplish those jobs more effectively. By determining the specific SBG capabilities that improve a user’s ability to complete a specific job, RTI assessed where and how SBG could provide the most improved outcomes and value. This study assessed the “jobs to be done” of select users, understanding their unique needs and providing qualitative and quantitative valuations of the key benefits SBG capabilities might bring.

# Executive Summary—Value Chain

Assessing the user needs and valuation for a future SBG mission involves considering the entire value chain for EO data (see graphic below). The target audience of this user-centered study—the end-user decision-makers—are several steps removed from sources like NASA. Thus, understanding the value chain of participants is important, and for this reason, RTI’s research targeted end users but also intermediary product developers, service providers, and boundary organizations that have both specific technical insights and knowledge of their respective application domains. This study also sought to assess the maturity of EO data use and specifically hyperspectral imaging spectroscopy (HIS) and combined TIR imaging, used by end users and intermediaries. Early-stage innovators and lead users in established “communities of practice” were identified for potential collaboration. Pathways to further engage and support early adopters that are less mature, but promising “communities of potential” have also been noted for each select “primary” application area. By engaging and soliciting insights from across the value chain and for communities of varied EO and HIS adoption maturity, a comprehensive and broadly inclusive SBG assessment was possible.



Earth Observation Data Value Chain






**End users** ultimately want EO-based tools and services that help them make better decisions for preparation, planning, and policy. For end users, the needs and value vary greatly by application and end-user organization type. This study sought to target diverse users by primary application area and gain insights about their specific needs, SBG capability priorities, and the prospective value of SBG compared with current methods. Over 30 end users were interviewed, and a significant number were surveyed.

**Intermediary VASPs** and other boundary organizations provide a critical link between the scientific and research data providers and private sector end users. VASPs create the services and products used in the SBG primary application areas and provide unique insights about practical considerations of SBG applications and capabilities. Over a dozen VASPs were interviewed and many more surveyed, bringing a strong commercial perspective to the findings.

**NASA** plays a critical role in the EO value chain as mission leaders, scientific and research data providers, and application developers. Numerous NASA SBG and experts were consulted throughout this effort.

# Executive Summary—Application Focus

RTI's structured research process ([Appendix II](#)) was designed to divergently consider a wide range of SBG-relevant applications and then systematically investigate and report on the user needs and potential benefit SBG might bring to various EO user communities. However, a focused and detailed investigation required that the research be limited to only a select set of SBG-relevant primary application areas. Starting from the DS science objectives and SBG Science Applications Traceability Matrix (SATM) and additional secondary research, the collaborative SBG/RTI team used detailed evaluation criteria to narrow the areas to four primary application areas. These primary application areas strategically span the full range of SBG science objectives while also enabling the user-centered research and valuation assessment work to be effective and timely.

Building from DS & SBG SATM		Down-Selected Applications for Consideration		Primary Areas Selected or Study	
Decadal Survey	Prioritized Application Categories	Preliminary Application Examples	Narrowed Set of Application Examples	FINAL Primary Applications	
Terrestrial Ecosystems	CR—Conservation & restoration	CR1—Conservation of biodiversity CR2—Invasive species CR3—Restoration of coastal habitats	CR1—Conservation of biodiversity DR1—*Fire risk mapping, response	DR1—*Fire risk mapping & response	 Fire Ecology and Risk
	*DR—Disaster resilience & response	DR1—*Fire risk mapping, response DR2—*Volcano: mapping, detection, response			
	VH—Vegetation mapping & health	VH1—Ag crop health/stress/damage mapping VH2—Forestry/timber mapping/health/disease VH3—*Drought: mapping, detection, response	VH1, 3 Ag/crops/drought WR1—Water: Usage	VH3—Drought monitoring/mapping in agriculture	 Agriculture and Water Resources
Hydrology/ Terrestrial	WR—Water resource management	WR1—Usage, ag irrigation/water use efficiency WR2—Supply (snow/cryosphere)			
Aquatic Ecosystems	*WQ—Water quality monitoring & response	WQ1—*Algal bloom detection & response WQ2—Aquaculture/fishery health/invasive species WQ3—Power plant cooling/water temp	WQ1—*Algal bloom monitoring & response	WQ1—*Coastal algal bloom monitoring	 Algal Bloom and Water Quality Mapping
Terrestrial/ Weather	UHP—Urban/health planning	UHP1—*Heat wave/islands/mitigation UHP2—Vector-borne diseases (via veg/soil/water and temp)	UHP1—*Heat wave/mitigation UHP2—Vector-borne diseases	EN1—Mineral/energy resource composition & mapping	 Mineral Resource Mapping
Active Surface Geology	EN—Energy/natural resource management	EN1—Mineral/energy resource composition & mapping	EN1—Mineral/energy resource composition & mapping		
General Applications	Data usability/data access	Data software and data providers	* Low latency		 VASPs

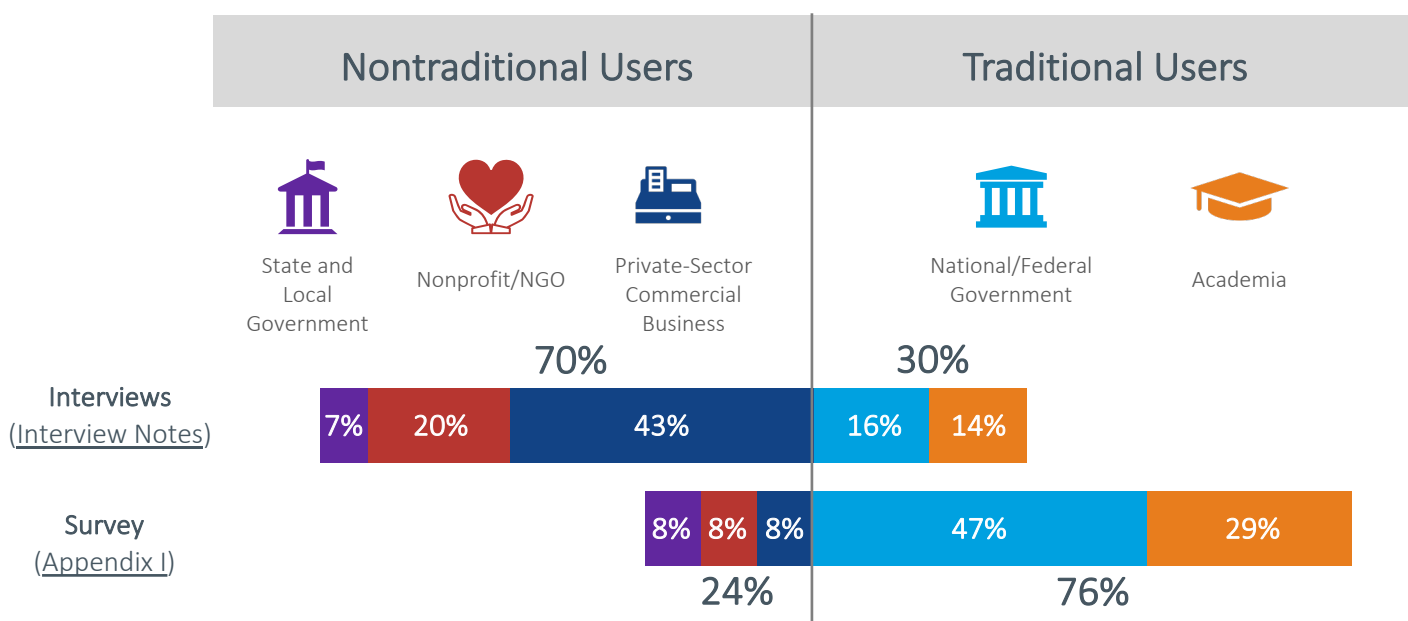


# Executive Summary—User Types

A fundamental aspect of the user study was to engage private-sector, nongovernmental organization (NGO), and local municipal EO users not traditionally engaged by NASA for science mission planning. **Categorically identifying and engaging this type of nontraditional user was paramount to successfully studying their needs.** The engagement process can be especially challenging and time intensive when seeking “nontraditional” users who neither identify themselves as such nor understand the technical capabilities of SBG. The RTI/SBG team worked to clarify useful categories such as direct vs. research users of EO data, operational or commercial users vs. scientific or academic developers of EO data products, and technical vs. nontechnical. With this understanding, **we targeted a diverse and representative set of user types across the value chain for each of the four primary application areas.** RTI/SBG used an iterative process of identifying and engaging users by:







- *Considering relevant applications’ characteristics of the end-user EO activities*
- *Interviewing an initial set of application experts, including observers and users, to start to build hypothetical value propositions for SBG*
- *Using early insights on hypotheses about other potential use cases and end users*
- *Down-selecting to preliminary user communities to gain greater understanding on value*
- *Selecting representative users to interview and user communities to survey*
- *Building on insights to refine the user community and user-persona descriptions*

Demographics of User Inputs



# Executive Summary—Users and Use Cases

Identifying and characterizing specific potential users and the use cases for SBG in each primary application area was also a central part of this study. SBG offers significant potential benefits across each of these areas, but the “jobs to be done” for each user community are unique, and the applied science and decision-making tools they need will all require substantial development for today’s innovators and future early adopters. **The wide variety of potential uses and private- and public-sector users underscores the broad utility of SBG (see Findings and Appendices).**

Primary Application	 Example Potential Users of SBG Data/Products	 Key Use Cases of SBG Data/Products
 Fire	<ul style="list-style-type: none"> <li>• State and local fire authorities/responders</li> <li>• Commercial utility companies</li> <li>• Fire risk map/model developers/providers</li> <li>• Prescribed burn companies and regulators</li> <li>• Insurance companies</li> </ul>	<ul style="list-style-type: none"> <li>• Pre-/post-fire fuel mapping of vegetation type, live/dead, moisture for risk severity</li> <li>• Fire risk model via better fuel/moisture data</li> <li>• Utility vegetation management, risk mitigation, and operations/planning changes</li> </ul>
 Agriculture	<ul style="list-style-type: none"> <li>• Ag input and equipment companies</li> <li>• Crop consultants, large-farm managers, commodities traders, and insurers</li> <li>• Ecosystem market communities</li> <li>• Ag/water resource/policy managers</li> </ul>	<ul style="list-style-type: none"> <li>• Ag and water resource, drought monitoring</li> <li>• Crop type/composition/health monitoring (for ag policies, supply chain, input optimization)</li> <li>• Crop residue/monitoring (e.g., for credits, monitoring, reporting, and verification [MRV])</li> <li>• National food security/yield forecasting</li> </ul>
 Algal Blooms	<ul style="list-style-type: none"> <li>• Local health/enviro./water agencies</li> <li>• Aquaculture (fish/shellfish) companies</li> <li>• Drinking water utilities/engineering firms</li> <li>• Forestry/lake management companies/orgs</li> </ul>	<ul style="list-style-type: none"> <li>• Regional-scale water body quality monitoring</li> <li>• Early warning of harmful algal blooms (HABs)</li> <li>• Shellfish site water chemistry for growth/health</li> <li>• Watershed/source pollution/nutrient monitors</li> </ul>
 Mining	<ul style="list-style-type: none"> <li>• “Spectral geologists” and exploration consultants for large mining companies</li> <li>• Regulatory/compliance organizations</li> <li>• VASPs serving the energy and mineral resources sectors</li> </ul>	<ul style="list-style-type: none"> <li>• Greenfield/brownfield large-area explorations</li> <li>• Geologic process, mineral/vegetation surveys</li> <li>• Mine opening/operations baseline/monitoring</li> <li>• Environmental/health/regulatory monitoring on-site and in surrounding environs</li> </ul>

SBG is seen as unique and potentially transformative. Among leading innovators in the use of remote HIS and among skilled VASPs, there is a desire and even excitement for an SBG-type mission. **The opportunity for a satellite-based global hyperspectral VSWIR and multispectral TIR mission is quite compelling to those who understand SBG’s scientific and applied potential.** Such users were able to assess and prioritize SBG capabilities.

# Executive Summary—User Needs

The expert interviews and survey data provided insights about user needs for and perceptions of SBG capabilities. For each primary application area, this table summarizes a general assessment of users' most desired EO spectral imaging capabilities, SBG fit with needs, user community HIS adoption maturity, and SBG's most promising uses.

## Legend:

Users' assessment of the ability of an SBG capability to meet their needs in their priority applications:

- Is a significant benefit addressing unmet need(s)
- Is benefit that adequately meets need(s)
- Does not meet need(s) in some application(s)
- Does not meet need(s) in key applications

^ Latency <48 hrs - only if matched with useful revisit rates

**Notes:** Analyses of user-rated *importance of specific observational capabilities* (hi-low) and SBG "*fit with user needs*" (color dots) are based on a composite of all user (interview and survey) findings by primary application area. Given the different applications and user communities, relative comparisons among application areas are not advised. Findings in each area should be considered distinct, though not mutually exclusive.

Capability		Agriculture/Water Resource			Algal Bloom/ Water Quality			Fire Ecology/ Fire Risk			Mineral Resources		
Importance		Hi	Med	Low	Hi	Med	Low	Hi	Med	Low	Hi	Med	Low
Spectral	VIS-NIR	●			●			●			●		
	SWIR		●			●			●		●		
	TIR	●			●				●			●	
Spatial	VSWIR	●			●			●				●	
	TIR	●			●			●			●		
Temporal	VSWIR	●			●			●					●
	TIR	●			●			●					●
Coincidence			●			●			●			●	
Sensitivity			●		●					●	●		
Latency^		●			●			●					●
Sector Adoption of HIS Today				●			●			●		●	
SBG's Top Opportunities <i>fit with application; low satisfaction with current solutions</i>		- Crop type/ composition/health monitoring - Cover residue/crop monitoring			- Aquaculture farm siting/monitoring - Wide-area water quality monitoring for health			- Pre-fire fuel mapping/risk modeling			- Global new "greenfield exploration" - Local existing "brownfield" exploration		
Comments		Interview/survey findings were not well aligned. Divergent prioritization based on several different cross-sector applications.			Interview/survey findings were loosely aligned. Prioritization is based upon a few very different cross-sector applications.			Interview/survey findings fairly well aligned. Prioritization based only on pre- and post-fire applications. SBG is not ideal for active fire.			Interview and survey findings were very well aligned. Prioritization based heavily on two top priority exploration applications.		



HIS – hyperspectral imaging spectroscopy; VIS-NIR – visible to near infrared; SWIR – shortwave infrared, TIR – thermal infrared

# Executive Summary—Value Proposition

Today’s community of skilled EO spectral imaging practitioners is relatively small compared with the extensive set of future potential end users. This small group of current HIS and TIR imaging **innovators and lead users sees great potential for SBG, but they also have very practical and operational use considerations.** SBG offers highly desired spectral capabilities but has practical limitations in terms of spatial resolution and revisit rates, especially, for example, in dynamic and complex agriculture crop and water quality monitoring applications. Additionally, private- and public-sector end users envision directly using HIS-enabled data products, models, and support services to accomplish their “jobs to be done” in day-to-day operations and decision-making, not for applied research. This study’s findings are about user needs for current and future “jobs to be done”; we did not ask what kind of research or science they would desire.\* **Operational use is where nontraditional users will get the most value from SBG, so NASA must consider ways in which to provide support to lead users and eventual early adopters.**

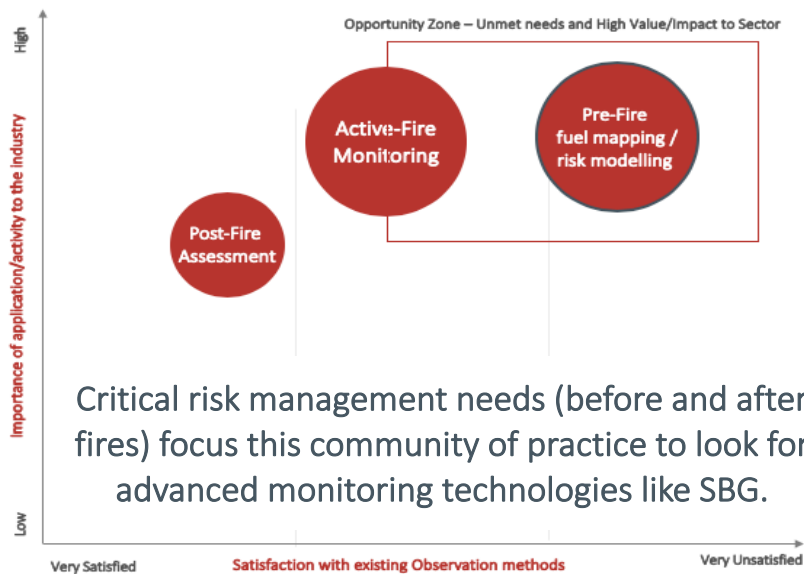
A key part of NASA SBG’s value proposition is that users trust NASA’s credibility and capabilities to ensure **high-fidelity data, transparent data processes, verification, and accessibility.** Innovators and VASPs, in particular, noted the great value NASA could provide by advancing HIS applied and data sciences and by taking a leadership role in developing and ensuring information quality. Findings show the high importance users across applications place on information quality factors.

	Not at All Important		Slightly Important		Moderately Important		Very Important		Extremely Important		Do Not Know	
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %
Cloud-free, usable imagery	0	%	2	1.5%	3	2.2%	37	27.0%	95	69.3%	0	%
Latency^	2	1.4%	11	7.6%	40	27.8%	54	37.5%	37	25.7%	0	%
Data continuity	0	%	5	3.4%	14	9.5%	60	40.5%	69	46.6%	0	%
Data and data product	0	%	4	2.7%	25	16.9%	52	35.1%	66	44.6%	1	0.7%
Data quality	0	%	0	%	6	4.1%	49	33.1%	93	62.8%	0	%
Information cost	3	2.0%	7	4.8%	21	14.3%	29	19.7%	84	57.1%	3	2.0%

^Latency – For general and application-specific user needs findings about latency, see [Appendix I](#).

# Executive Summary—Fire Ecology & Risk

**Community Overview:** The fire ecology and risk management community of innovators and early adopters is seeking advances in observation technologies and is open to HIS and TIR capabilities. This is a relatively small, cohesive, hierarchically connected, and risk– and liability management–driven community, which engages federal and local entities to map fire risk and use established channels to drive pre-fire and post-fire mitigation. Climate change, drought, and costs of wildfires spur industry interest in advanced technologies. Experts think SBG could significantly improve fire risk mapping and models. There is not a large or well-established commercial sector built around fire ecology, but companies see the efficiency gains of large remote-area monitoring and improved modeling.



**The NASA/SBG Opportunity:** Commercial entities experience liability exposure and are unlikely to develop remote sensing tools openly. NASA should work to integrate SBG into existing mapping programs and platforms operationally managed by other federal agencies to drive the value proposition and utility of SBG.

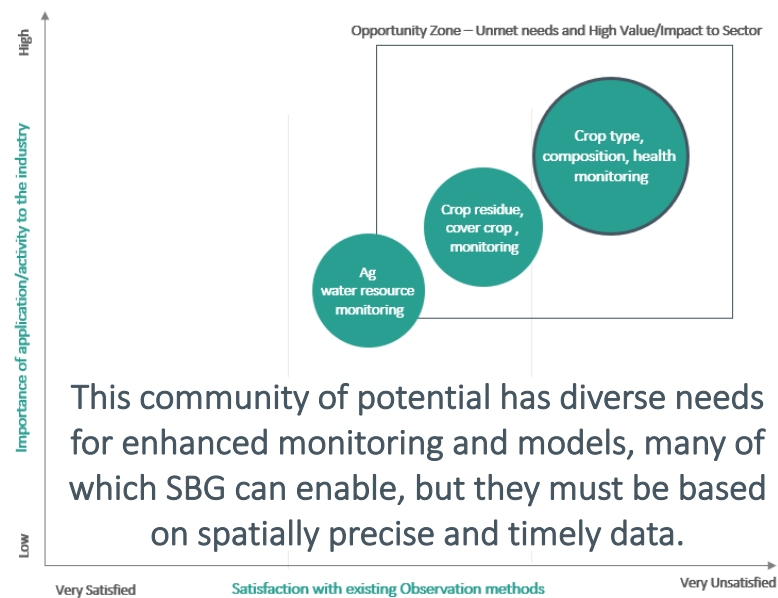
KEY SBG USE CASES – BY VALUE IMPACT				
End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Electric Utility Companies	HIS data allow for more detailed fuel mapping that can, in turn, improve risk severity maps.	Reduced risk of fire outbreaks (via precise mitigation efforts)	Reduced liability costs from fire damages	High
	Improved thermal sensing and better fuel maps lead to more accurate simulation modeling.	Reduced fire damage/severity of impacts	Reduced labor costs for on-the-ground inspections/mitigation	
Policymakers/ State, Local Health Authorities	HIS capabilities allow policymakers to prioritize geographies better and take actions to prevent wildfires and pre-position resources for wildfire suppression.	Reduced on-the-ground work to prepare for fires	Reduced labor costs for on-the-ground inspections and/or pre-fire mitigation efforts	Medium
	Thermal data allow better tracking of where prescribed fire is happening to enable: <ul style="list-style-type: none"> <li>Tracking compliance with EPA NAICS standards (e.g., PM 2.5)</li> <li>Clarifying relationships between prescribed burns and wildfire incidence and severity</li> </ul>	<ul style="list-style-type: none"> <li>More precise prescribed fire interventions lead to fewer fires</li> <li>Reduced burn severity</li> <li>Improved air quality from compliance with air emissions standards</li> </ul>	<ul style="list-style-type: none"> <li>Avoided costs of suppression and emergency response</li> <li>Reduced social costs for mortality and morbidity</li> <li>Avoided economic and property losses</li> </ul>	
Land Managers	HIS/thermal capabilities enable underlying data sets for tools such as LANDFIRE ( <a href="http://maps.tnc.org/landfire/">http://maps.tnc.org/landfire/</a> ) to improve water resource management, more precise prescribed burns, and wildlife protection	<ul style="list-style-type: none"> <li>More precise prescribed fire interventions lead to fewer fires</li> <li>Improved land and water management decisions at landscape and watershed scales</li> </ul>	<ul style="list-style-type: none"> <li>Improved biodiversity conservation (from economically viable restoration activities)</li> <li>More abundant water resources</li> </ul>	Low

More detailed valuation case studies and vignettes can be found in the [Findings](#) section.



# Executive Summary—Ag and Water

**Community Overview:** This is the most diverse community of potential studied, with users across commercial, environmental, and policy groups in globally diverse low- to high-income regions. Yet one common trend prevails: the need for more advanced monitoring and models, which creates a strong interest in SBG capabilities. Precision and “right practice at the right place” farming are used to increase yields, conserve soil, and develop new ecosystem service offerings. These highly localized practices demand better crop, soil, moisture, and other data to enable these new pursuits, which SBG can help enable. Managing scarce water resources requires better models and monitoring to improve forecasting, usage, and decision-making. SBG has huge potential to advance these tools but will be held back by limited temporal revisits and the need for plant-scale (<5 m) spatial resolution.



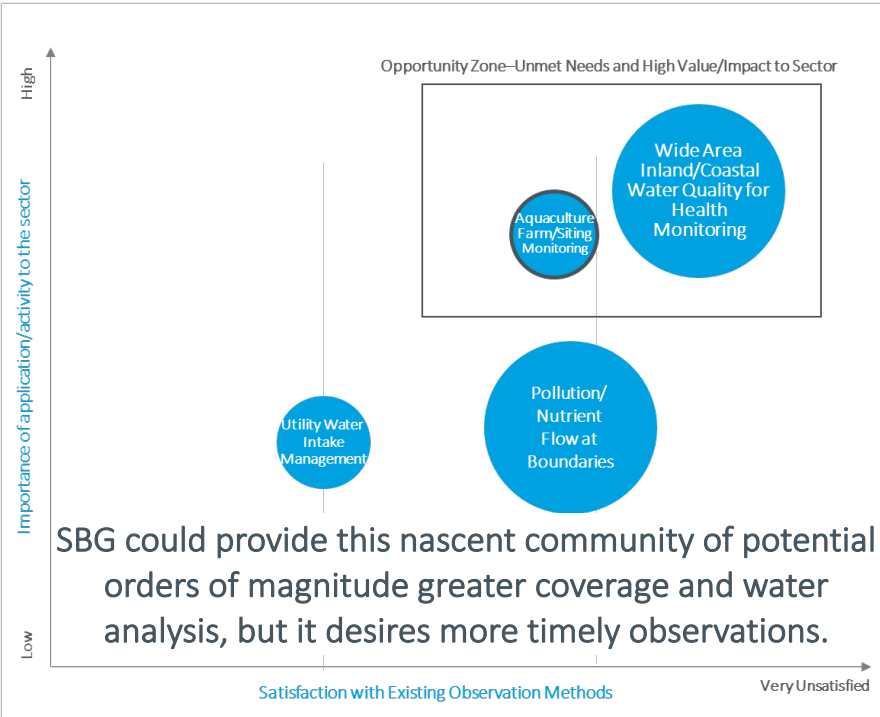
**The NASA/SBG Opportunity:** NASA should support the evolution of HIS-applied science and model development across many agriculture, conservation, and water management projects to engage this emerging and diffuse global community of potential.

KEY SBG USE CASES – BY VALUE IMPACT				
End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Commercial/Technology-oriented Farmers	HIS data that identify plant composition will improve precision agriculture in the form of: <ul style="list-style-type: none"> <li>• More precise and dynamic input applications</li> </ul> TIR data enable more precise estimates of <ul style="list-style-type: none"> <li>• Data products for water/irrigation management</li> </ul>	Increased net benefits to farmers due to improvements and expansions of precision agriculture adoption and, in particular, variable-rate applications	Increased yields (higher revenues) and reduced input costs due to the ability to more precisely apply inputs and maximize yields throughout the growing season	High
Public Sector and NGOs Promoting Climate Change Mitigation/Ecosystem Services	HIS data enable improvements in mapping cover crop type and residue mapping to better target and incentivize conservation practices with multiple ecosystem service benefits.	Federal and local governments can better target conservation incentive programs to areas of higher risk  Scaled MRV for conservation programs  Removed barriers to scaling ecosystem services in agriculture	Reduced cost or removed barriers to developing verified emission reductions  Value of increasing carbon offsets  Reduced nitrogen and agrochemical pollution	Medium/High
Commercial Agricultural Companies and Crop Consultants	Hyperspectral data would allow agricultural input companies to: <ul style="list-style-type: none"> <li>• Optimize their supply chains to farmers’ needs</li> <li>• Improve precision agricultural technology offerings to farmers</li> </ul>	Input provision companies can pre-position their representatives to provide advice and sell inputs..  Agriculture equipment manufacturers can improve their technological tools and offerings	Reduced supply chain costs (e.g., labor)  Increased sales of agricultural inputs and technology	Medium

More detailed valuation case studies and vignettes can be found in the [Findings](#) section.

# Executive Summary—Algal Blooms and H<sub>2</sub>O

**Community Overview:** The algal blooms and water quality domain comprises distinct subcommunities of potential, with isolated groups of HIS innovators. Inland and coastal user communities have clear monitoring needs where SBG could bring great benefit. However, entrenched water quality monitoring and industry methods, combined with limited resources and incentives, mean basic water safety monitoring suffices. SBG would improve the scale of useful monitoring by orders of magnitude for time-series studies of susceptible water and shellfish farm siting. Yet the daily changes of algal blooms and estuary systems mean SBG is not adequate for the most important health- and safety-driven user activities identified.



**The NASA/SBG Opportunity:** NASA should support the evolution of HIS for water-applied science and demonstration projects. Ground truthing and in-field sampling are under-resourced but required, so NASA should consider ways to fund, ensure, and integrate these observation methods with SBG to advance commercial and state agency uses.

KEY SBG USE CASES – BY VALUE IMPACT				
End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Local Municipalities and State/Local Health Authorities	Better models/early detection of blooms	Reduced time to public notification	Reduced health care costs	High
	Improved identification of HAB species/colonies	Fewer illnesses and death	Social value of morbidity	
Shellfish Farms	Better detection of water temperature and food sources for optimal siting of farms	Increased productivity/yield of farms	Increased production Increased financing for industry growth	Modest
Salmon Farms	Better water temperature detection for siting in areas with lowest probability of a “super chill” event	Reduced fish loss from a super chill event	Increased production Increased financing for industry growth	Modest
Water Utilities	Managing intake and treatment systems when blooms approach	Optimal timing of switching between multiple water intake sources	Reduced operating costs and need for chemicals	Low
Policymakers and Land Use Monitoring Organizations	Development, monitoring, and enforcement of land use policies to reduce nutrient runoff into streams and lakes	Reduced nutrient runoff into streams and lakes	Less economic loss due to fewer HABs	High
	• Monitoring of vegetation and riparian buffers	Reduced algal blooms in streams and lakes	• Tourism • Property values	
	• Monitoring agricultural and livestock activities adjacent to water resources	Reduced algal blooms in coastal areas fed by these streams/rivers	• Aquaculture productivity • Human health impacts	

# Executive Summary—Mining Resources

**Community Overview:** Of the communities studied, the mining sector appears to be the most mature and sophisticated in the use of remote sensing imaging and the most receptive to the potential of SBG. This is a cohesive and sophisticated user community driven by large competitive players largely motivated by economics. A new generation of spectral geologists skilled in advanced digital tools wants next-generation observation platforms for high-value exploration applications. The industry particularly values SBG’s SWIR and TIR spectral resolution at very high signal-to-noise ratios (SNRs). These same capabilities will enable broader operational use or new applications in this sector if priority exploration needs are met. This sector is least concerned about short revisits or latency but wants operational, quality data.



**The NASA/SBG Opportunity:** The value proposition NASA brings for this community is to ensure very high-quality, transparent, and reliable data and data platforms via missions with multiyear durations and operational, not just research, utility. NASA could engage them immediately because mining companies are ready for HIS mineral exploration today, but they will look to other missions and options as they become available.

KEY SBG USE CASES – BY VALUE IMPACT				
Use Cases	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Exploration and Discovery	Regional surveys of greenfield areas and targeted local site brownfield exploration	Hyperspectral and TIR at scale: Large-area and local hyperspectral data on target mineral and alteration signatures	Reduced time and cost of large-area and target area exploration	High
	Combined mineral and vegetation exploration (geobotany) mapping			
Mine Opening and Operations	Vegetation monitoring for operational impacts	More comprehensive coverage and greater precision of monitoring activities	Lower operating costs and avoided environmental and health incidents	Modest
	Monitoring hazardous fugitive dust during operations			
Mine Closing, Reclamation, and Monitoring	Monitoring acid water leakage from mines	More comprehensive coverage and greater precision of monitoring activities	Avoidance of environmental penalties and poor public relations  Reduced risk of catastrophic events	Modest
	Monitoring structural integrity of mining dams and tailing stacks			

More detailed valuation case studies and vignettes can be found in the [Findings](#) section.

# Executive Summary—Observations

**Lessons learned from this project will help NASA with user-centered engagements going forward for SBG and other missions.** Having concluded this user-centered approach over the past 6 months, collaborating with many NASA experts, and engaging dozens of EO service provider practitioners and end-user experts, we have learned some key lessons that will be useful to consider for future efforts. In response to these learnings, RTI is testing additional engagement strategies for extended outreach with the other DOs and refining and optimizing research methods.

**Close collaboration between NASA SBG Application Team leads and RTI was essential.** Using a select set of SBG SATM-derived primary applications provided focus, and the SBG team's expertise in translating the SBG capabilities for subsequent user assessment was critical. Using NASA expert networks enabled RTI to engage users at different points across the value chain, which provided unique intermediary and end-user perspectives on a range of key topics for this study. Through the RTI and SBG Application teams' collaborative efforts, we were able to successfully frame and test SBG's technical and application-specific value propositions to the right kinds of users. This close collaboration between RTI and NASA SBG Application leads was essential to successfully target user needs and desired SBG capabilities specifically in the context of, and as a timely key input to, the broader SBG architecture study.

**Targeting end users takes time, but the research methods were effective.** RTI found that expert contacts provided through personal referrals by NASA representatives or community contacts were generally quite receptive and enthusiastic about providing their time and insights. However, achieving a few more degrees of separation from the scientific community to reach private-sector end users proved challenging. Reaching these "not traditionally engaged users" required extensive networking and outreach. This outreach work and research must be done intentionally with users across applications, and their unique perspectives and input must be put in context of where they sit in the value chain. Understanding their motivations for using EO platforms and their awareness (or not) is a key finding for consideration. Developing a sense of the user personas, needs, and valuations can then follow.

# Executive Summary—Observations

**Valuation resources are limited, and additional studies are warranted.** During this study, including interviews with expert economists and our concerted literature reviews, it became apparent that there is a dearth of studies on the value of EO data and even fewer in the primary application areas that could inform SBG valuations. As such, RTI had to rely almost solely on industry and boundary organizations for their speculative estimates and then look to supporting data to form basic valuations. This approach, and the use of clearly articulated “baseline” capabilities, provided an effective value estimation for SBG, but more comprehensive studies are warranted should NASA want to value its final SBG architectures. Additional valuation studies assessing other SBG application areas, or carefully selecting a known area for more rigorous valuations would provide much needed validation. Additionally, one of the challenges of asking end users about the benefits and value for missions like SBG some 10 years in advance is that it may be too early to realistically articulate the functionality end users might gain. As such, more specific fixed capabilities and evidence of the utility will help improve future assessments. It is also important to consider the value derived at different parts of the value chain or in the marketplace. Outside of specific applications, we did get overall estimates of the commercial market for HIS data. Commercial mission planners estimate the total market for global HIS data sets (not combined with TIR and assuming <15-m spatial resolution) to range from \$500M to \$1B annually. These values though are very speculative because no such capability yet exists.

**For SBG to yield value beyond the science it will require development work by NASA.** Ultimately, to meet the objectives of creating socioeconomic value from NASA EO missions, it is clear from this SBG study that NASA will have to actively lay the groundwork and build the communities within industrial sectors and application domains so that they may fully leverage the SBG capabilities. While smaller targeted programs may advance HIS applications, for broadly enabling and sustained development, and true value creation, a full mission like SBG is likely necessary. There are many potential applications and arenas for value creation for SBG, which extend well beyond what this pilot study could explore, but the findings of this study suggest strong potential. High-level findings related to value are offered for each primary application with notes on how NASA might approach those user communities to address their needs and enhance value.



# Executive Summary—Recommendations

RTI recommends that SBG continue to advance its effort to engage end-user communities by working on four thematic areas: coordination, communication, competency, and collaboration. To proactively leverage strong sector communities of practice and build up communities of potential, SBG will need to extend its efforts to find, engage, educate, and partner with these communities.

## Coordination

NASA has many active and proposed EO missions that are seeking to more actively engage different user communities. Along with SBG, the other DO missions are charged with engaging nonresearch communities in many of the same applied science and end-user application areas. The US Geological Survey and National Oceanic and Atmospheric Administration have similar efforts and many of them are trying to engage the same types of user communities. During this study, RTI was cautioned about and observed the occasional sign of user outreach “burnout.” Certain users receive multiple calls and get multiple needs surveys. At the same time, NASA needs to maintain the support of the “usual suspects” in boundary organizations, but also get further beyond them and find new users to engage in an organized manner.

*“I have trouble keeping up with all of the missions, but I am always glad to talk to NASA because I have a relationship with NASA researchers, but I also hear from other programs and get their surveys too.”*

—State Water Quality and Ecology Manager

NASA should continue to push outreach efforts to new nonresearch end-user communities. Organizers for programs for cross-mission efforts like the Disasters Program, early adopter and DEVELOP programs, and user community efforts of many current and proposed missions are also great models and resources for outreach to new user communities. However, there is a need to consider how to centralize and coordinate such programs to create shared visibility and coordination in finding and engaging these communities productively, especially in areas of overlapping mission objectives and applications. RTI’s support of other DO missions is one new effort where coordination of shared user communities might begin.

## Communication

NASA SBG is very good at communicating with and engaging the research community. The current SBG website is informative, and open meetings and outreach are sustained and effective, but they do not speak the language nor are they designed to engage the nonresearch end user.

*“I am a meteorologist by training, and we are investing a lot to build our fire risk mapping tools, but I do not know what hyperspectral or TIR is or understand what it can do for me.”* —Utility Company Fire Risk Lead

NASA SBG should consider developing more nonresearch user-specific communications that help “translate” the technology and science of SBG into clear and user-relevant content that helps new user communities and less technically sophisticated users understand the potential benefits of the SBG and other DO missions. Most potential users of SBG lack understanding about spectral imaging. Our interviews also revealed that several EO experts had no experience with HIS. Despite this, NASA has much it can build on. NASA Applied Science’s DISCOVERY effort has looked at more effective communication strategies and methods. NASA’s technology transfer program (T2P) can leverage its extensive experience doing “technology translation.” T2P has established resources to do this type of outreach and already serves as a portal for basic remote science tools and data products. In this project, RTI worked with the SBG Applications team to develop “example and evidence” demonstration briefs to help technical and nontechnical interviewees learn about and better assess SBG capabilities. An intentional focus on developing these kinds of technology translation and application-specific “user benefit” communication tools will help bridge the awareness gap to a broader set of nonresearch user communities.

# Executive Summary—Recommendations

## Competency

The SBG mission is unique but is built on a legacy of hyperspectral and TIR imaging missions. RTI's research indicates that very few outside of a small set of industry spectral scientists, for example, spectral geologists in the mining community, have expertise in HIS. To further develop communities of practice and help build the engagement of potential communities, NASA should consider ways to expand and sustain the HIS competency of current spectral and application specialists by supporting their application development tools. NASA should also consider providing training and capacity building specifically for nonspecialist decision-makers looking to understand and leverage prospective SBG data products in their application areas. A lack of awareness and literacy with HIS will be a significant barrier to SBG adoption and socioeconomic value creation.

***“Right now most people are not even great at looking at multispectral maps and what models (e.g., ET models) are telling them, let alone hyperspectral data cubes.”***

—Fire and Agriculture mapping specialist

An SBG early adopters' program and other efforts to build the competency of nonresearch end users will be critical. Various federal agencies have “experts in residence” programs that place application and technology specialists in private-sector companies to advance commercial product and service development. NASA might look to these various models as a way to do training and capacity building related to HIS data, platforms, and derived models so that these companies can be much better informed lead users for a future SBG mission.

This user-centered study characterized private- and public-sector users, their needs and SBG capability priorities, and valuation cases for four representative application areas. This kind of user engagement should continue with a broader set of user types and user communities to inform ongoing SBG architecture and data product developments. To go beyond meeting SBG's science objectives and truly have broader socioeconomic impact, NASA will need to actively nurture, build, and support a wide range of these user communities to ensure those communities are willing and able to convert SBG data products into socioeconomic impacts.

## Collaboration

As noted, the applied science of SBG requires sophisticated data and tools that must be advanced in different application areas before SBG can realize significant socioeconomic value. Additionally, data science, computing, and modeling technologies involved in making SBG data accessible and useful will surely advance significantly over the next 5 to 10 years as the SBG mission planning progresses.

***“I am relying on scientists to develop production ready, defensible, data product and models I can use today.”***

—Water Management and Policy Director

Although the use of spectral imaging in mineral exploration and fire risk fuel mapping appears to be mature, other areas such as water quality, biology, chemometrics, and plant composition still require significant further applied science development. Specialists such as spectral geologists and agronomists are excited and “hungry” for the capabilities SBG could provide and should be targeted as co-innovators and lead users. Thus, NASA will need to consider ways to actively extend collaborations with and support to researchers and intermediaries developing HIS in different application areas. Furthermore, the data science and information management platforms and model development will not likely diffuse into the nonresearch community without active, direct, and ongoing collaboration with target user communities and organizations. NASA should consider strategies to expand collaboration efforts like the early adopters' programs to target longer term applications and data science collaborations and to help mature communities of potential, including commercial use case collaborations.

# Project Overview

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Project context and research elements

# Context

The Surface Biology and Geology (SBG) Designated Observable (DO) mission is in direct response to the 2017 National Academies Decadal Survey (DS).

The National Academies 2018 DS<sup>1</sup> outlines the science and DO missions that NASA will explore for the period of 2017-2027. The survey designates that one DO pursue global imaging spectroscopy measurements. NASA is proposing to meet this directive with an SBG DO mission and investigation.

The SBG investigation<sup>2</sup> will address global science themes including flows of energy, carbon, water, and nutrients sustaining the life cycle of terrestrial and marine ecosystems; the variability of the land surface and the fluxes of water and energy; inventory of the world's volcanoes and observations following eruptions; snow accumulation and melt; water balance from the headwaters to the continent; land and water use effects on evapotranspiration (ET); functional traits and diversity of terrestrial and aquatic ecosystems and vegetation; and more.

The SBG mission is intended to include global observations using hyperspectral imaging spectroscopy (HIS) measurements in the visible to shortwave infrared range, coupled with 5-day thermal infrared (TIR) measurements from 8–12 microns. Both measurements would offer repeat coverage on approximately a 5-day TIR to 16-day visible to short wave infrared (VSWIR) cadence, with comprehensive coverage of the globe's coastal and terrestrial area. This would bring an unprecedented volume of data with the potential to transform spectral remote sensing science and applications.

By late 2019, the SBG team had gone through preliminary design phases and in 2020 was in Phase 2 architecture down-selection studies. Beyond designing SBG architectures to meet the science themes noted, the DS also calls on NASA to engage private and public users to enable SBG to potentially address a broader set of applications and support societal and industry objectives. The subject user study was completed as part of the Phase 2 studies in conjunction with the SBG Architecture and Application working groups' efforts.

# Objectives

SBG teamed with RTI International to assess the user needs and socioeconomic value of proposed Earth observation applications.

Per the National Academies DS and as one of the planned NASA DO missions, the NASA SBG Applications team must assess the socioeconomic value of proposed EO applications and possible architectures to prioritize system functionality and capabilities to drive SBG architecture design decisions. To help inform the Phase 2 “community assessment report,” the SBG Applications team set the following high-level objectives for the subject research and assessment effort and to support SBG’s architecture decisions:

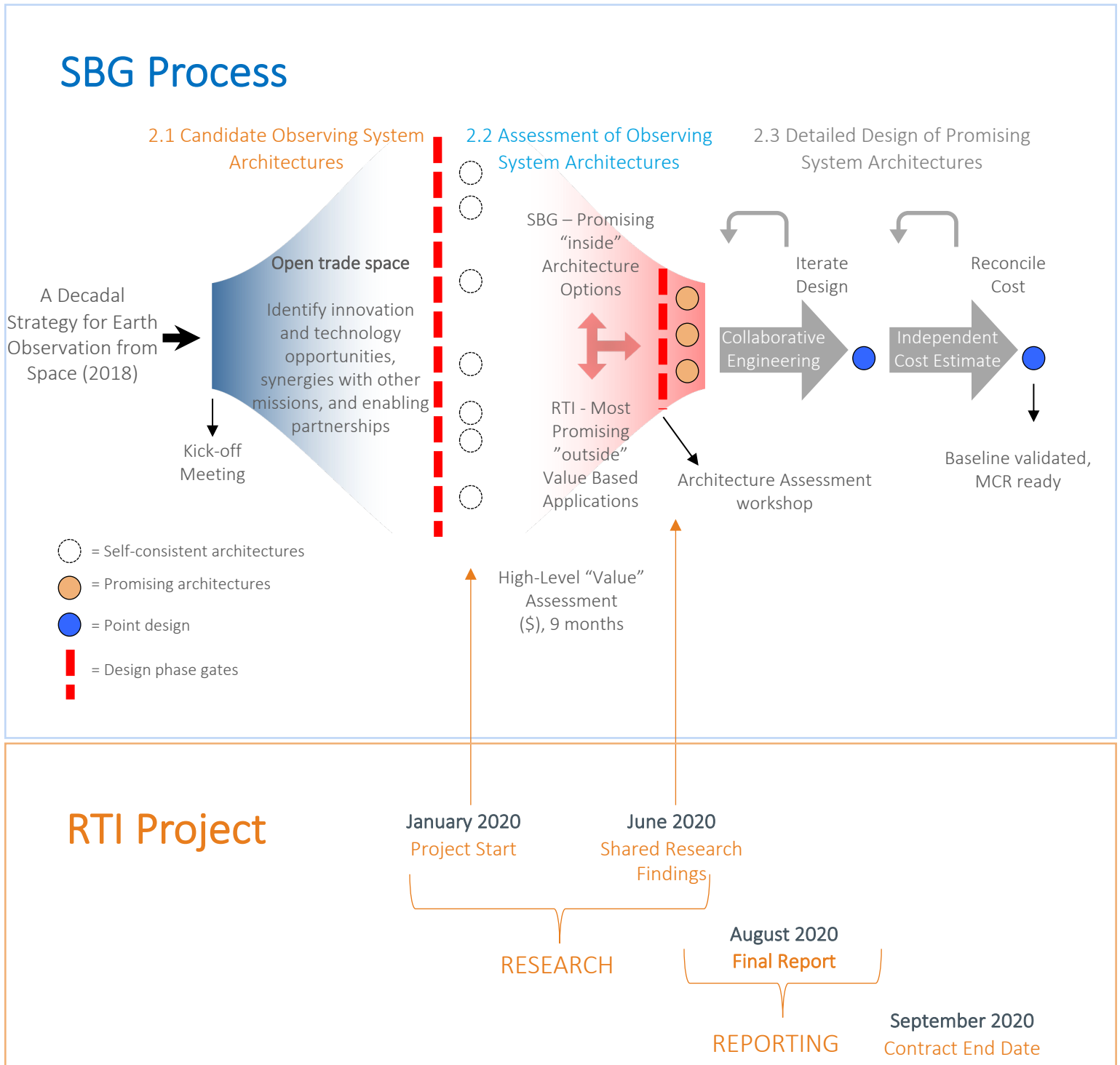
- Employ a user-centered approach to engage the EO user community and characterize and confirm a set of target EO applications that align with SBG objectives.
- Develop a repeatable value-based analytics methodology, use it to assess the baseline value of capabilities for SBG EO systems, value of target applications, and if possible, assess the prospective value of SBG data outputs to target application user communities.
- Determine the associated SBG observation platform technical functionality and capability attributes for the highest value target applications.
- Use the combined value analysis and functionality analysis of the highest impact and most SBG-relevant applications to directly inform the SBG design process.

To address this need, RTI assembled a team of technologists, user-centered design practitioners, and economists who collaborated closely with the NASA DO SBG Applications team to guide and integrate the research and findings throughout. RTI used a user design-driven framework—desirability, viability, and feasibility (DVF)—to define the primary work streams. RTI focused on key user-centered variables: desirability—priority EO applications and end-user needs—and viability—socioeconomic valuation for priority applications. The NASA team owned considerations related to the last user-centered variable: feasibility—technical capabilities. See [Appendix II](#) for more detail on the user research approach.



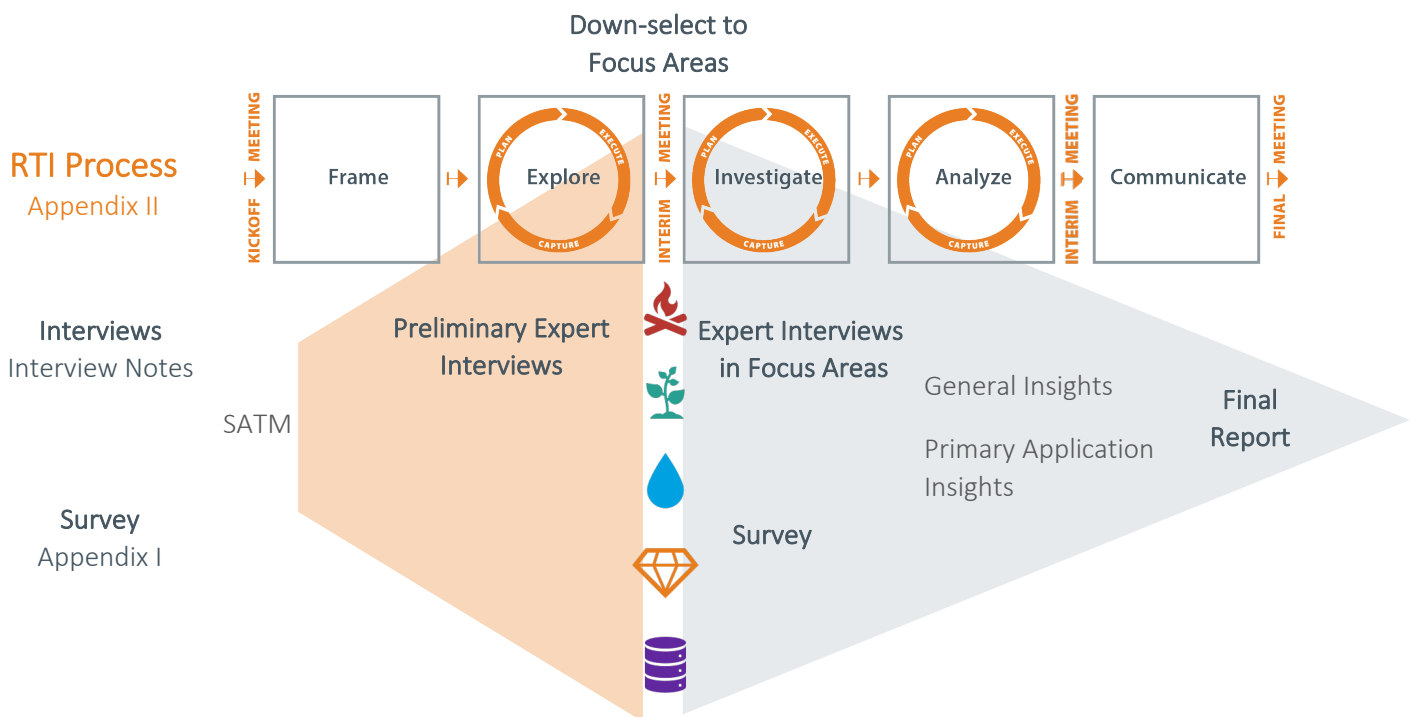
# Timing

RTI's research occurred over 6 months coinciding with SBG's architecture down-selection phase.



# Research Methodology

The RTI approach leveraged secondary research, user interviews, and a survey to gain general and application-specific input.



SBG applications and users were broadly considered, then specifically targeted for detailed investigation. A set of “primary” applications was essential to focus the research effort. The project process ([Appendix II](#)) leveraged input from NASA, secondary research, and primary research in the form of interviews and a survey. Early technical expert interviews helped the team consider target end users, promising application areas, and key SBG functionalities. These interviews, aligned with the valuation approach, helped the down-selection process to the primary areas of focus: fire ecology and risk, agriculture and water resources, algal blooms and water quality, mineral resources, and value-added data services. Extensive end-user interviews ([Interview Notes](#)) brought forward more nuanced and detailed nonresearch end-user insights, whereas the survey ([Appendix I](#)) provided input from a much larger set of traditional research users, which generated more semi-quantitative data on needs and desired SBG capabilities. The input from the varied efforts is combined in this report to help bring broader understanding of user needs, value, and prioritization to directly inform SBG design decisions.

# User Needs and Valuation Research

A diverse but targeted set of experts and user communities across the value chain were engaged in the research effort.

The research effort specifically sought to engage users not traditionally engaged by NASA to inform mission design. The project developed and executed an end-user outreach engagement plan to target a variety of nonresearch, direct users with specific objectives for each interaction. Specifically, we needed to reach users who represented specific:

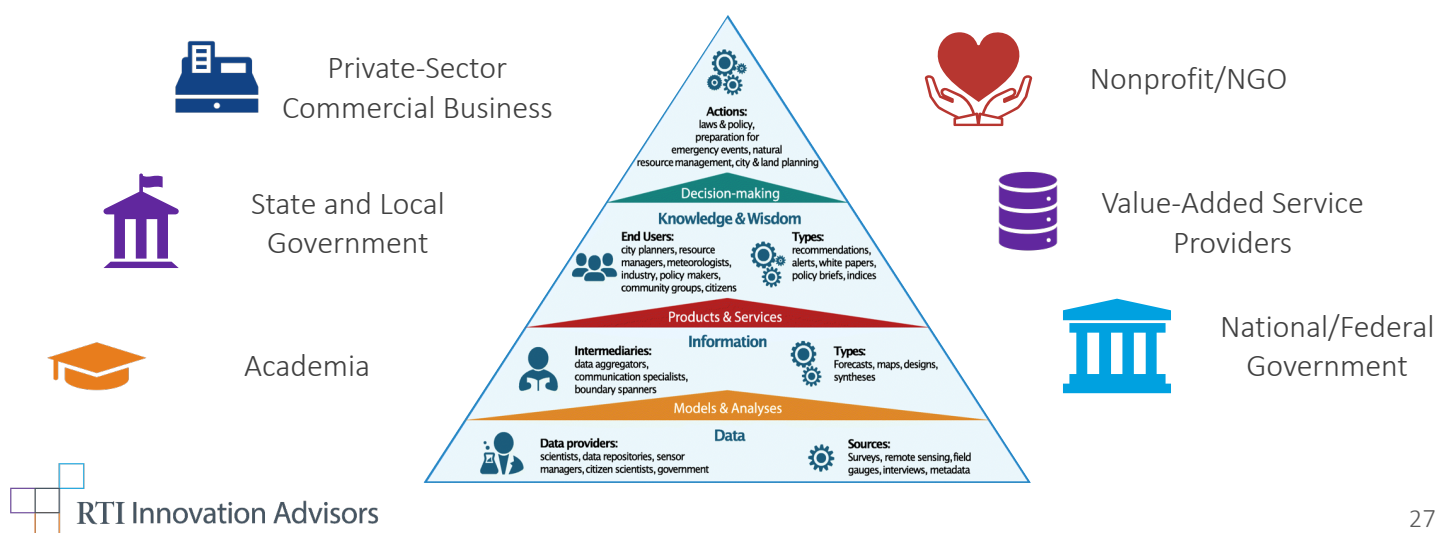
**Application areas**—Knowledgeable and active in the targeted application domains and industries and familiar with the use, benefits, and drawbacks of current EO systems, such that they could articulate needs and priorities

**Levels of expertise**—Sophistication (or not) about remote sensing and imaging spectroscopy

**Value chain levels**—To assess perceived needs and SBG value by producers and users of EO data and data products

**Perspectives**—Science, research, commercial data use, data product development for private and public target segments, and ultimate end users within commercial firms, nongovernmental organizations (NGOs), trade associations, and local agencies

We worked closely with SBG experts and their science community contacts to identify two key resources for our search: key informants and user community representatives. To engage the varied target users and experts, we developed explanatory materials, structured interview guides, and surveys to query them.



# Valuation Methodology

The research effort built hypothetical value propositions to compare currently used observations to SBG capabilities.

**Valuation studies tested an application and user-specific SBG value proposition against current EO methods.** For each application area, RTI posed a hypothetical question about how the SBG mission might provide value to users by interviewing user experts and investigating their current operating practices and the current remote sensing data uses. For example, in many applications Landsat 8 and Sentinel 2 are used to support their observations (baseline practices). With SBG's capabilities, new data and products will be available to enhance these observations. It is the comparison of the existing baseline observation methods with the incremental improvements of the prospective SBG capabilities that determines the value to end users. When possible, we always used current remote sensing imaging, not ground-based direct methods, as the baseline.





**End users provided valuation estimates.** When interviewees (nontraditional users or nontechnical experts) had less technical expertise, we posed questions in terms of what incremental benefits SBG capabilities and utility could bring to key example activities (e.g., fuel mapping [fire], crop type [agriculture]). Then we let the experts focus on where they saw the greatest potential for SBG to provide value to the subject user communities. After honing in on the high-value applications or individual case studies, we probed if the experts would be able to ascribe any quantitative estimates with which we could characterize the incremental value of SBG enhancements. These estimated were then validated.

**Existing values data were used to validate estimates.** Valuations are based on both expert and cited data. For each application area, we chose the “high-value” case as our principal case study but included additional “vignettes” to describe other applications for which SBG could provide value to user communities. Although case studies were validated with multiple methods and experts, principal case studies and vignettes should be considered very rough estimates. The valuation of a final SBG architecture warrants additional substantive research.

# Primary Applications Valuation

Understanding baseline user methods and activities enabled a comparative valuation of SBG benefits.

**Assessing the currently used (baseline) EO methods of users was a key part of the valuation method.** For each of the four selected primary application areas, we considered a brief summary of baseline activities; these typically use, or are limited by, current remote sensing and EO data.


Baseline Activities	
 Fire	As technical experts discussed how SBG could enhance fire risk models or restoration, we asked commercial users to quantify this improvement. We had found data on utility company expenditures on current remote sensing technologies, so we could extrapolate how the improvement on fire risk models would translate into reduced liabilities for utility companies.
 Agriculture	Agriculture water/drought and crop health/stress monitoring involves many different sub-applications. For application spanning improvements to residue monitoring, precision farming, or variable-rate application technology (VRT), we probed further about the percentage improvements over current methods. When possible, we used existing estimates from literature and cited data, so we applied the estimated improvements to current methods.
 Algal Blooms	Current activities and use of remote sensing vary greatly across organizations monitoring algal blooms and water quality. Shellfish and salmon farms use little to no remote sensing data. Organizations monitoring oceans and large lakes use satellite information but augment it with substantial amounts of in situ measurements. Organizations/communities monitoring smaller lakes and rivers/streams rely completely on in situ or field study monitoring, which is not scalable and is inadequate for regional coverage.
 Mining	Mineral composition mapping for greenfield and brownfield exploration activities relies heavily on ground-based sampling and laboratory testing. In selected small-scale applications, fly-overs are conducted or commercial satellite data are purchased, but both are very costly, which significantly limits their use. In other ongoing mining operations and restoration applications, physical sampling and monitoring are the costly norm and can only be done locally so they are not currently seen as viable for routine multisite use.

# Interview Methodology

Enhanced interview methods brought greater understanding of “nontraditional” users’ needs and priorities.

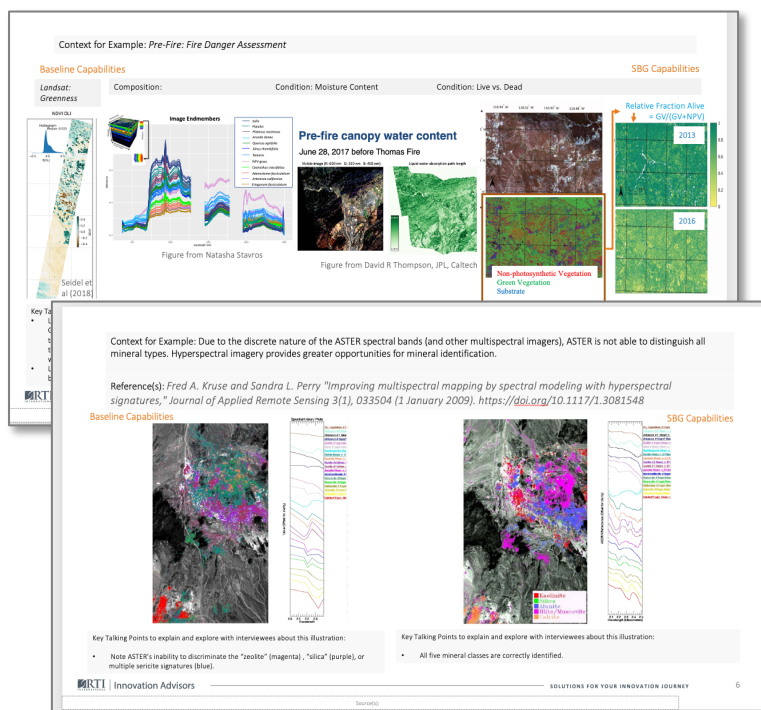
The RTI team developed and used a structured but flexible interview guide to facilitate and capture consistent insights on key users, user needs, priority SBG capabilities, and applications valuation research points. Additionally, we used documents to highlight SBG value propositions and facilitate communication with experts and users. These decks visually demonstrate the features and capabilities of SBG and how they might bring value to the primary application areas.

## Interview Guide

Name here Title	Brief bio
	
<b>Key User Groups</b> (customers)	
<b>Application Area, Key Use Cases</b> (jobs to be done)	
<b>Current Methods Used/Limitations</b> (unmet needs)	
<b>Key SBG Capabilities/Priorities</b> (potential benefits)	
<b>Ideal Capabilities</b> (potential benefits)	
<b>Key Value Indicators/Resources</b> (potential impact)	
<b>Other Insights</b>	

RTI Innovation Advisors 63

## Communication Tools



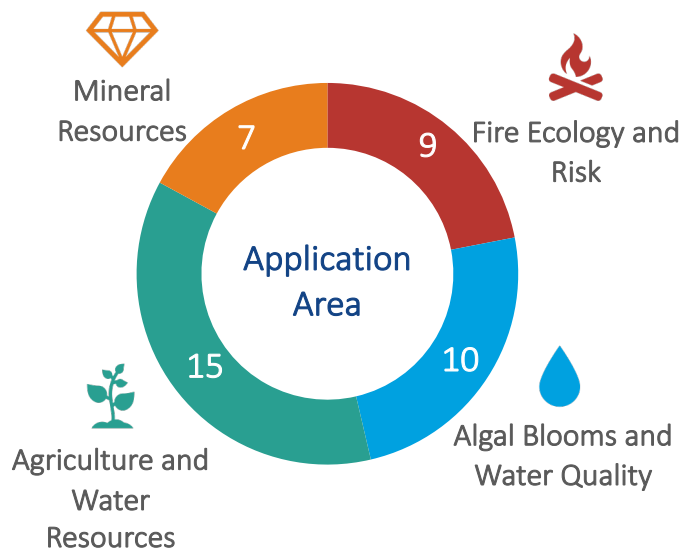
The communication tools, illustrated above, helped drive consistency and quality of interviews, which are documented in Interview Notes, provided as a separate file to the SBG Applications Team. These interview notes are a rich resource, loaded with contextual and nuanced insights and are expected add value and information to the NASA SBG Applications team, potentially beyond the scope of this project.



# Interview Demographics

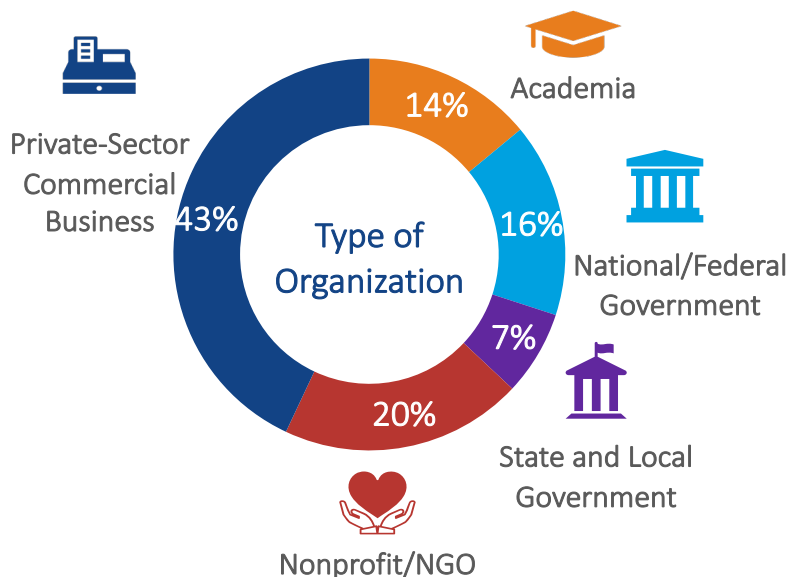
Over 40 different “key informant” users and experts shared their insights about primary application areas and user communities.

Interviews  
by Application Area



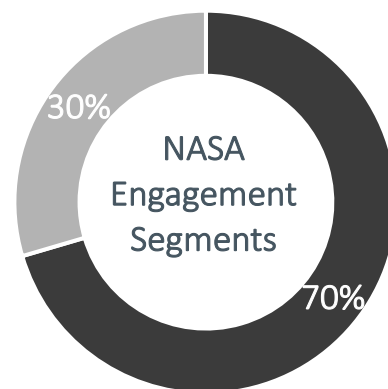
Only those key informant interviews with specific and distinctive insights on needs, capabilities, and value estimates have been summarized (see [Interview Notes](#)).

Interviewee Breakdown  
by Organization



Interviewee  
by User Type

30% Traditionally Engaged Users  
National/Federal Government, Academia



70% Nontraditionally Engaged Users  
Private-sector commercial business (inclusive of commercial value-added service provider), nonprofit/NGO, state and local government

# Survey Methodology

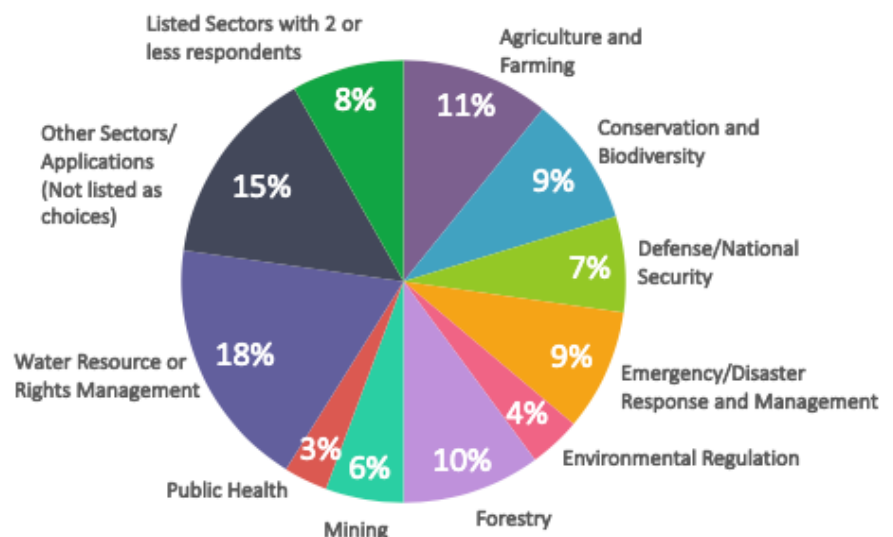
A custom online survey, which was aimed at primary application user communities, provided diverse and quantitative findings.

After reviewing past surveys related to EO needs from organizations including the US Geological Survey (Landsat) and European Space Agency, RTI developed a survey design document to plan the architecture and key lines of query for the SBG user needs survey. The survey was ultimately designed to probe into two specific assessment aspects: (1) general user needs and (2) insights about the SBG relevant primary application areas. The survey design was reviewed with the SBG team for accuracy and intent before it was launched.

In parallel to survey development, the RTI/SBG team engaged user community sponsors, identified for each application area, as an avenue to connect to survey participants. The final custom online survey instrument was distributed via email, social media posts, and sponsor websites and remained open for responses between June 9 and 23, 2020. Survey insights and summary charts, beyond the information captured in Key Findings, are provided in [Appendix I](#). A large majority of respondents came from organizations that NASA might traditionally engage for scientific and applied research efforts. However, approximately one quarter of respondents were private and NGO organizations not typically engaged by NASA. These groups provide a statistically significant set of responses.

The respondents represented a diverse and fairly balanced distribution of cross-industry participation, which suggests that the survey was successfully and widely distributed, and the survey results are not overly biased to one sector or another.

What is the primary industry sector or domain focus of your organization?



# Survey Demographics

More than 500 respondents from over 20 user communities provided a broadly representative set of responses.

21

User Community Groups  
Engaged for the Survey

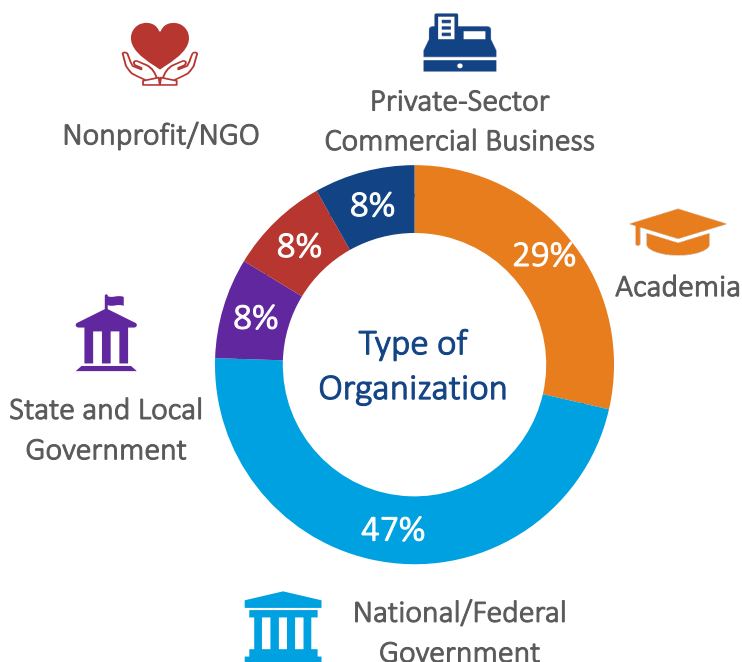
562

Total Unique Survey  
Respondents

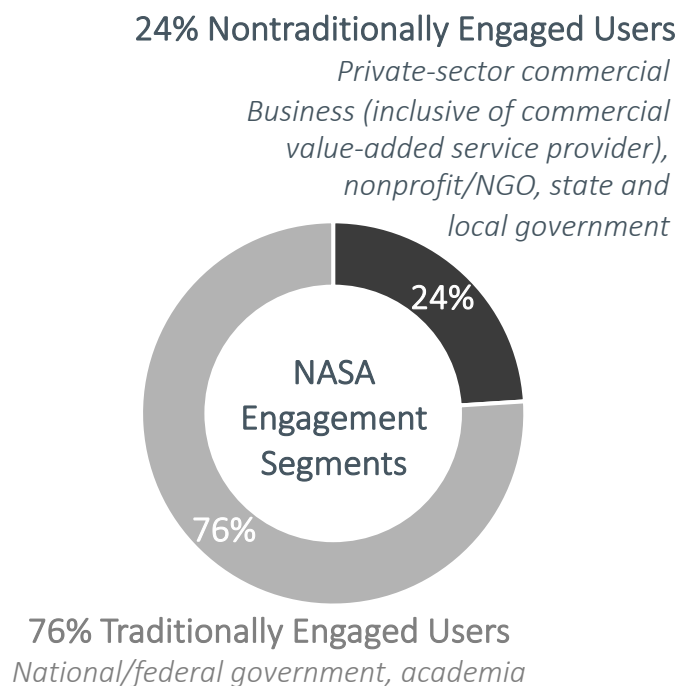
## Survey Completion Rates



## Survey Respondents by Organization Type



## Survey Respondents by Engagement Segment



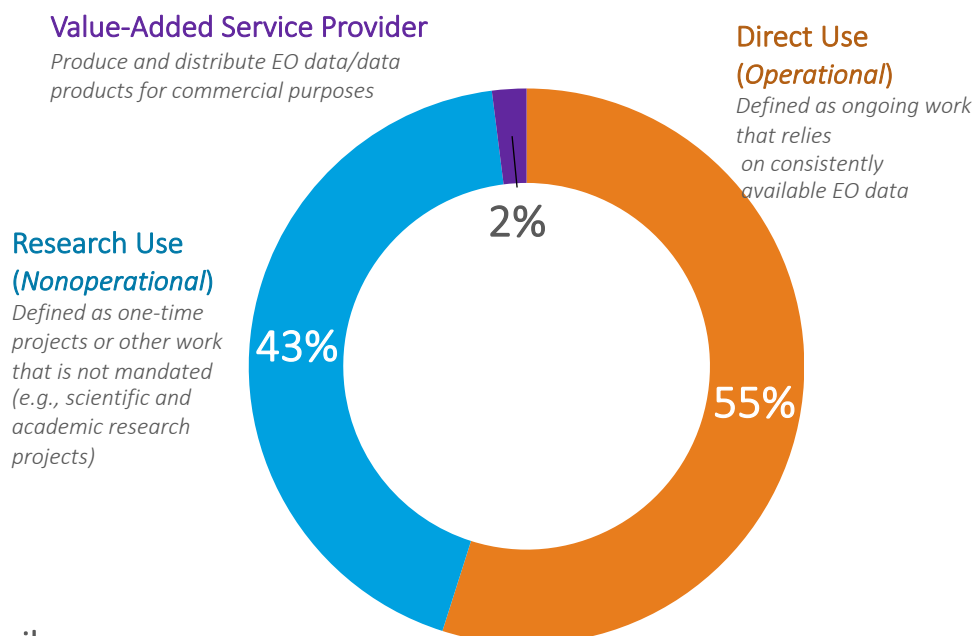
# Value Chain Demographics

The survey and interviews reached a balance of research and direct users and consumers of EO data.

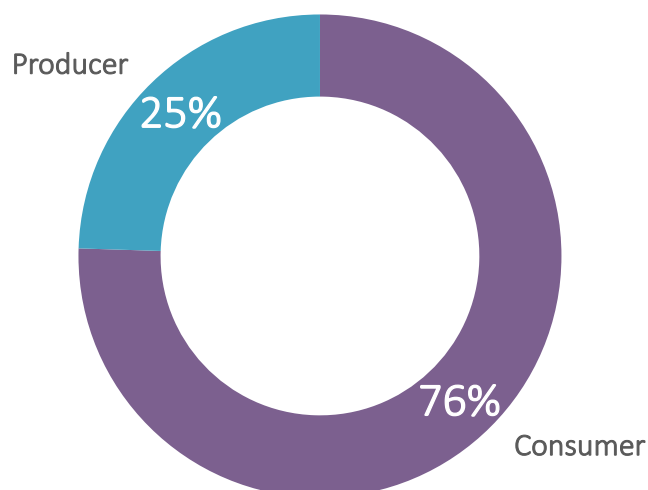
The survey probed how respondents typically engage with, consume or produce, use, and prioritize the use of EO data to understand their position in the value chain. This understanding allowed RTI to better assess the application, needs, and priorities of different EO data user types.

Respondents were an equal spread of direct (operational) users and research (nonoperational) users. The near-even split of these two key user groups provides a simple mechanism by which to compare their needs and priorities and is used as part of the survey's "General" section analysis.

What kind of work do you do with EO data and data products?



Which of the following best describes your use of EO data products?



The high percentage of EO data consumer respondents suggests that the survey reached its intended audience of "users." This, along with the diverse range of respondent organizations and balanced group of user types across survey and interviews, indicates the insights come from a representative set of users from which viable conclusions can be drawn.

# Findings

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Overarching insights and  
specific findings for selected applications

# Findings

Findings from all research methods have been distilled to highlight user insights and value for each primary application area.

The following sections summarize the synthesized and analyzed research findings and are organized by primary application area. For each area, the section offers:

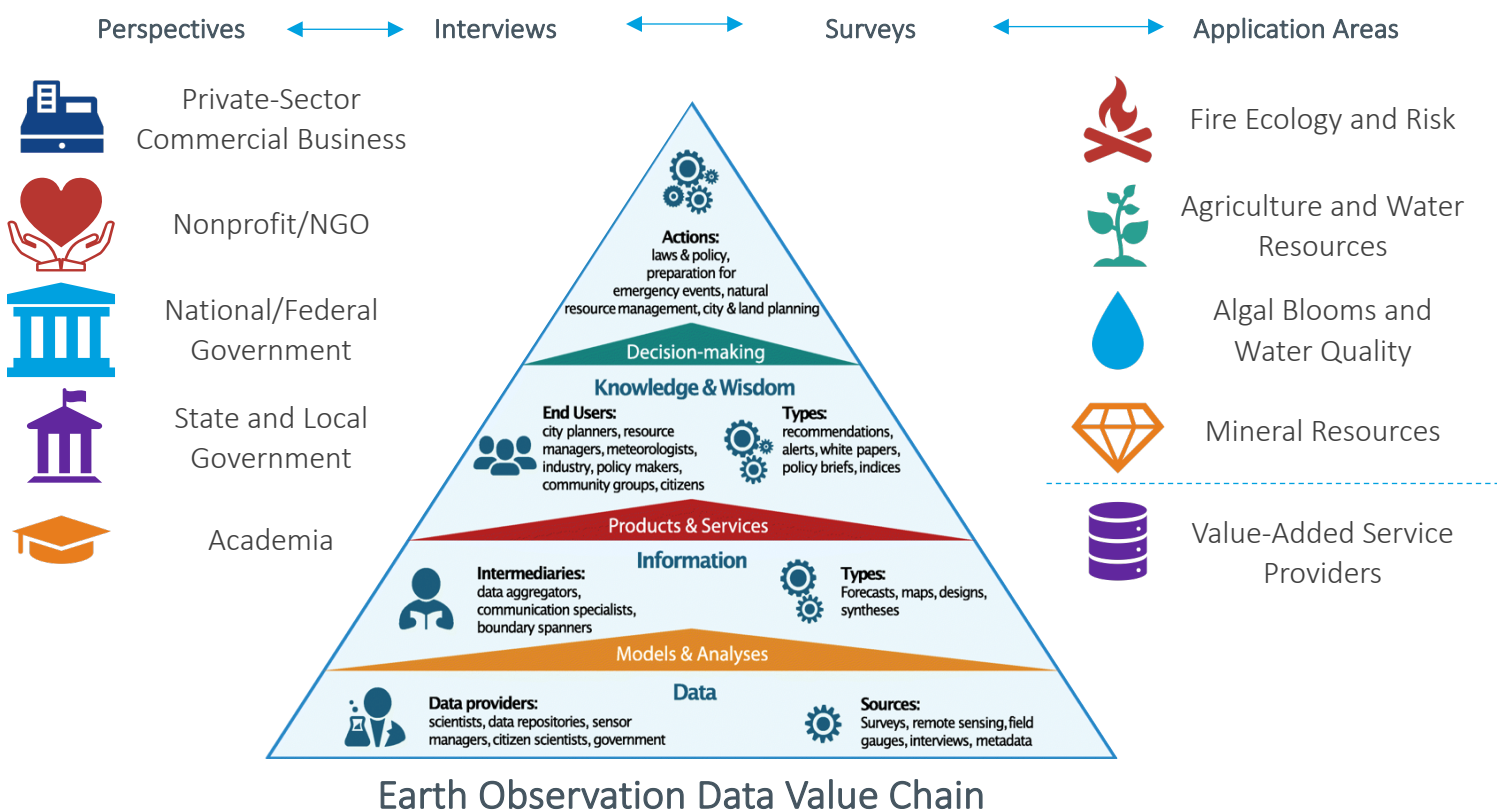
- User community overview
- User community high-value applications and user-based assessment of SBG capability fit and prioritization for those applications
- User persona profiles for key value chain participants
- Valuation context
- Summary analysis of application impacts and valuation
- Top application opportunities for SBG
- Valuation case study and vignettes

Brief insights are also provided specific to value-added service providers (VASPs).

## Appendices

- List of interviewees (Interview Notes are provided in a separate file.)
- Selected survey results (additional results are in Appendix I)

## SYNTHESIS OF KEY FINDINGS AND VALUATION





# Fire Ecology and Risk



# Fire Ecology and Risk—Community Overview

Users need better fire risk maps and models and SBG may help.



## Key Potential Users of SBG

### Data/Products

- State and local fire authorities and first responders
- Commercial electrical utility companies
- Fire risk mapping and modeling developers
- Government fire management agencies and laboratories and academic fire ecologists
- Forest, rangelands, grasslands land, fire response, and conservation managers
- Prescribed burn companies and regulators
- Insurance companies



## Key Use Cases of SBG Data/Products

- Fuel mapping via vegetation type, live/dead, moisture for risk severity maps
- Fire simulation modeling via improved fuel loading and moisture data sets
- Utility company vegetation management and risk-based operations modifications
- Prescribed burn planning and management
- Post-fire severity, fuel load, and regrowth mapping

**An urgency to the need for better fire risk maps and models.** Climate change, extended droughts, and the costs associated with wildfire have accelerated and focused agency and industry interest in advanced technologies to help assess fire risks, plan mitigations, and change operational procedures to better respond to these increased risks. Led and coordinated by government agencies, current fire risk mapping and models are based on remote sensing data, but experts believe SBG could significantly improve these. Commercial entities see the value of large remote area monitoring to augment other fire monitoring methods. Still, they are not likely to take on the liability of openly developing or supporting these new remote sensing tools.

**Addressing a few well-defined activities focuses this community of practice.** The fire ecology and risk management community is organized and coordinated in their response efforts and has a command-and-control aspect to it that is unlike other user communities. There are well-established regional fire risk agencies and convening bodies. Still, there is not a large or well-established commercial sector built around fire ecology like there is in other application areas. However, commercial entities like utilities and prescribed burn groups are very keen to use the best fire risk mapping toolsets available.

**Working to augment established groups and tools will increase access and value.** Because it is a small community filled with research experts, there is the potential for active partnering to set the stage for, and later adoption of, SBG data. NASA will likely want to actively work to integrate SBG into existing mapping programs and platforms operationally managed by other agencies.



# Fire Ecology and Risk—User Needs

SBG's advanced spectral capabilities will provide the detailed data needed to enhance key maps and models.



Fire ecologists, agencies, and risk model developers see strong potential for SBG's HIS and TIR resolution and see it as a significant improvement over current methods. Currently Landsat, Sentinel, MODIS, VIIRS are used by government fire groups, but the maps could be improved with updated fuel type, loading, moisture, and high-fidelity spatial data. SBG could enhance maps and risk models used by utilities and local agencies. Global coverage of SBG would enable better regional and targeted fire mitigation and operational responses.

The temporal revisits are inadequate for active fire monitoring, so pre- and post-fire are the best application areas. 30-m/100-m spatial resolutions are marginally adequate, but <10-m resolution is highly desired by experts and users. The sophistication of current fire simulations may make it possible to model the benefits of SBG performance over existing platforms.

## SBG Capability User Assessment—Fire Ecology and Risk

		Priority Applications		
		Pre-fire fuel load, risk mapping	Active-fire monitoring	Post-fire severity assessment
Spectral	VIS-NIR	✓	✓	✓
	SWIR	✓	✓	●
	TIR	✓	✓	✓
Spatial	VSWIR (≤ 30 m)	●	●	●
	TIR (100 m)	●	●	●
Temporal	VSWIR (16 d)	X	X	●
	TIR (3 d)	●	X	●
		Priority – High (H), Med (M), Low (L), Unknown		
Other	Coincidence	H	H	L
	Sensitivity	M	H	L
	Latency	M	H	L
	Global/Large-Area Coverage	H	M	H

### Legend:

- ✓ Is a significant benefit addressing unmet need(s)
- Is an adequate benefit that meets need(s)
- X Does not provide benefit or does not meet need(s)

### Users' Capability Priorities

(Listed in rough order of importance)

#### Spectral:

- NIS-VIR are highest priority for vegetation type, live/dead and moisture, ET, surface temperature
  - SWIR important for active fire
  - TIR lower priority

#### Temporal:

- Pre-fire 16/3 day is marginal, need 3–5 day as moisture/humidity changes
  - Latency should match revisit
- Post-fire 16 day is adequate
- For active fire 16/3 day is inadequate

#### Spatial:

- Spatial resolution is probably adequate
  - Could use <30 for better mapping/modeling of vegetation/urban boundaries

#### Coincidence:

- Nice to have for pre/post-fire but not critical at 16/3-day revisits. Would matter more in active fire if < daily revisits.

#### Sensitivity:

- Expect sensitivity is more than adequate for pre-fire and post-fire

# Fire Ecology and Risk—User Personas

SBG may help meet specific unmet data needs in large-area monitoring and advanced modeling and simulations.



## Local Agency

### State Fire Manager

We have to keep the public and commerce safe from fires and emissions. A big part of that is helping landowners and forestry entities use prescribed burns wisely. But we don't have the best tools to help our agencies guide prescribed burns.

We often don't even know when or where prescribed burns are happening, and we can't tell how it impacts the likelihood of wildfires. This uncertainty makes management hard. We could use the SBG data provided it feeds into the USFS maps we already use.



"Prescribed fire reduces wildfire, but without better data to support that we can't shape better policies and oversight."

## Commercial User

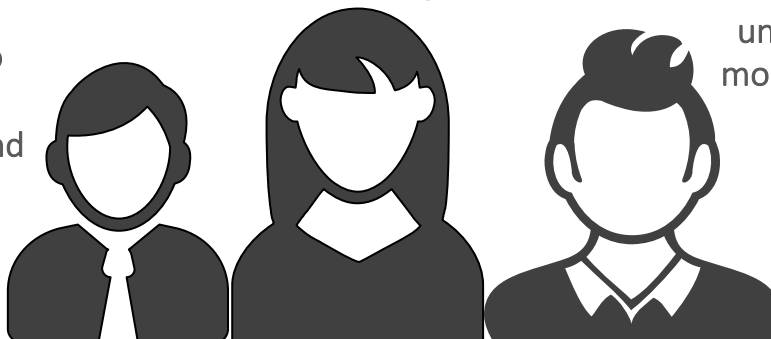
### Utility Company

Most of us are meteorologists first and just becoming fire ecology and risk management experts second.

We have no choice but to find better ways to find out where the fire risk is most severe and take mitigation steps. The conditions can change fast, so I worry about not having accurate maps and forecasts.

We need much more accurate RS moisture data at a higher boundary line of yard scale resolutions. But we have lots of other ground stations too. So we rely on other people's integrated models and maps.

"Improved fuel and moisture maps are the biggest unmet need, and they can't come soon enough."



## Value-Added Service Provider

### Fire Risk Model Developer

SBG could be a game changer for understanding fire ecology and improving fuel loading maps. With better SBG data, we could vastly improve our fire models and simulations.

Without accurate moisture and fuel type data, our models can be 90% off. That's what that happened in recent fires; the maps did not reflect reality.

Let's simulate SBG to show how much better it can be. But we have to make these tools easy and accessible to decision-makers.



"Right now most people are not great at even looking at multispectral maps or understanding what ET models are telling them."

# Fire Ecology and Risk—Valuation

## Observations Context and Challenges



Wildfires are one of the scourges of the United States, causing multibillion dollars' worth of damages annually, including massive destruction of property, draining of public resources, air pollution, and deaths. Climate change is exacerbating the problem. Given these huge damages, even marginal improvements in wildfire mitigation could have significant benefits for society.

### How can satellite data help?

Wildfires have been widely studied, and there is increasing recognition of the role that satellite EOs can play in enhancing fire mitigation. A recent study,<sup>1</sup> done as part of the NASA VALUABLES Consortium, showed how Landsat imagery could play a role in cost savings in post-fire response valued at \$35 million over a 5-period.

Experts said that SBG could provide significant socioeconomic value for fire mitigation, primarily in pre-fire preparation rather than active or post-fire response (see table on next page). During the pre-fire stage, improved fire risk mapping can help decision-makers take appropriate actions to mitigate fire risk and be better prepared for an outbreak.

### Challenges with current EO data products?

Experts also said that during the active fire stage, the situation is too dynamic for multiday revisit times to be useful. During the post-fire stage, SBG could be helpful, but the benefits are less straightforward or easy to quantify.

# Fire Ecology and Risk—Valuation

## Application Impacts



### Key SBG use cases:

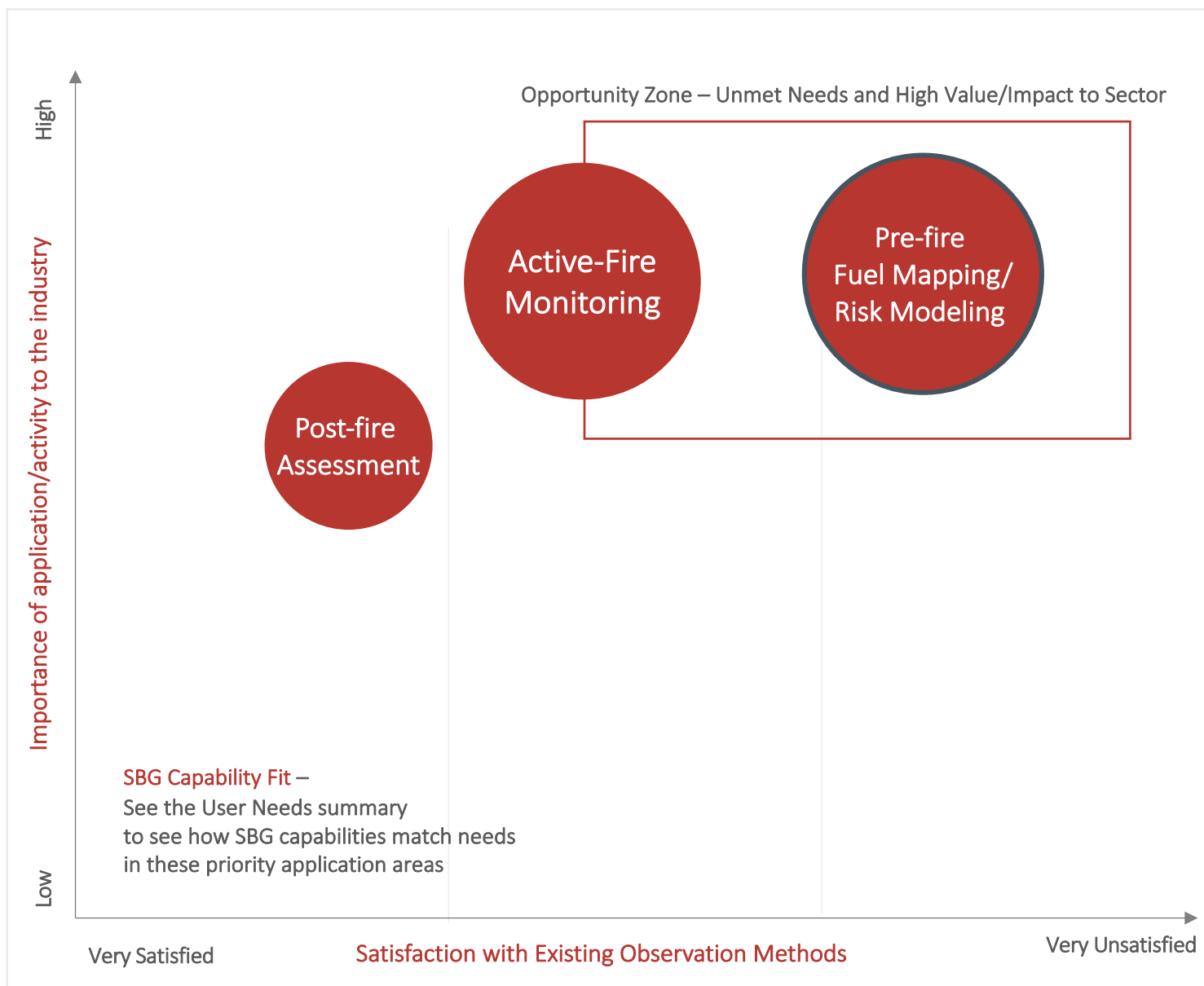
- Electric utilities could use SBG to take actions that would mitigate the risk of fire incidence. Although many factors contribute to fire outbreaks, we focused on utilities as a specific use case because of their outsized role in being held responsible for fire liabilities in recent years.
- Policymakers could use SBG-derived data to better track and monitor compliance and inform regulations related to prescribed fires.
- Land managers (e.g., conservation NGO) could use the enhanced evidence base that SBG provides (e.g., better data in LANDFIRE) to develop conservation plans and other ecosystem health decisions.

End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Electric Utility Companies	Hyperspectral data allow for more detailed fuel mapping that can, in turn, improve risk severity maps	Reduced risk of fire outbreaks (due to more precise risk avoidance measures)	Reduced liability costs associated with fire damages	High
	Improved thermal sensing and better fuel maps lead to more accurate simulation modeling	Reduced fire damage/severity of impacts	Reduced labor costs for on-the-ground inspections or pre-fire mitigation efforts	
Policymakers State, Local Health Authorities	Hyperspectral capabilities allow policymakers to better prioritize geographies and take actions to prevent wildfires and pre-position resources for wildfire suppression	Reduce on-the-ground work to prepare for fires	Reduced labor costs for on-the-ground inspections or pre-fire mitigation efforts	Medium
	Thermal data allow better tracking of where prescribed fire is happening to enable: <ul style="list-style-type: none"> <li>• Tracking compliance with EPA NAICS standards (e.g., PM 2.5)</li> <li>• Clarifying relationships between prescribed burns and wildfire incidence and severity</li> </ul>	More precise prescribed fire interventions lead to fewer fires Reduce burn severity Improved air quality from compliance with air emissions standards	Avoided costs of suppression and emergency response Reduced social costs for mortality and morbidity Avoided economic and property losses	
Land Managers	Hyperspectral and thermal capabilities can lead to better underlying data sets behind such tools as LANDFIRE ( <a href="http://maps.tnc.org/landfire/">http://maps.tnc.org/landfire/</a> ) used to improve water resource management, more precise prescribed burns, and wildlife protection	More precise prescribed fire interventions lead to fewer fires Improved land and water management decisions at landscape and watershed scales	Improved biodiversity conservation (from economically viable restoration activities) More abundant water resources	Low



# Fire Ecology and Risk—SBG Opportunity Zone

Areas with High Unmet Needs and Potential Value



Circle size indicates relative value of application.



The value impact of improved pre-fire risk mapping and modeling are enormous, and SBG holds a lot of potential to improve these methods. The case study looks at the value of this to one user group—commercial utility companies.

# Fire Ecology and Risk—Valuation Case Study

Just in improved remote sensing accuracy, SBG may have a value of >\$30M to larger utilities in fire-prone states alone.



Electric utilities have been found liable for numerous significant wildfires over the last decade, totaling billions of dollars. SBG has the potential to help utilities to better mitigate the risk of wildfires.

## Methods

PG&E was held liable for \$13.5 billion worth of fire damage over the period 2015–2018. PG&E’s 2019 Wildfire Safety Plan details more than \$800M of annual costs, including \$2M on remote sensing tools and models, representing approximately 0.25% of annual expenses. Assuming that this remote sensing cost (%) is equivalent to the role that remote sensing plays in mitigating fire risk, we then applied this percentage to historical liabilities and annualized them to approximate the inherent value that a major utility places on remote sensing. Based on expert interviews, we further assumed that SBG will represent a 20% improvement in accuracy over existing models and applied that percentage to the implicit value of remote sensing for PG&E. We then used utility data to scale this value to other fire-prone western states to arrive at an estimated value of SBG to mitigating fire risk for utilities across fire-prone states in the western US.

## Discussion/Assumptions

The SBG 20% assumption is key and a guess at this stage. It can be tested and refined through fire modeling scenarios like those that Technosylva, Inc. develops. The approach assumed that PG&E’s expenditures on remote sensing as a percentage of total costs are equivalent to the risk of future liability; this assumption needs to be validated.

### Case Study Value of SBG

We estimate that PG&E implicitly values satellite remote sensing at \$33.5M. Assuming that SBG improves these technologies by 20%, this represents a \$6.7M annual value. Using Energy Information Administration utility customer data to extrapolate to all fire-prone US western states (AK, AZ, CA, ID, NV, NM, UT, WA), this number grows to \$32.9M in annual benefits.

# Fire Ecology and Risk—Valuation

## Additional Valuation Vignettes



### Prescribed Fire—Value for Policymakers

Prescribed fire is an effective management tool used to promote balanced and resilient ecosystems and manage risks of uncontrolled wildfires. Unfortunately, prescribed fires often happen beneath a forest canopy, so they are hard to track. The best data on prescribed fires are currently found in the National Prescribed Fire Use Survey Report prepared by the Coalition of Prescribed Fire Councils. According to the lead author of this report, if SBG and its thermal sensors could help track prescribed fires, it would be a game changer for national- and state-level policymakers by:

- Allowing state agencies to prioritize and plan fire management more effectively
- Providing needed data to inform a national prescribed fire law (currently one does not exist)
- Providing regulatory agencies the data they need to track and regulate air quality, including particulate matter emissions
- Expand the evidence base needed to research the impacts of prescribed fire on ecosystem health and suppression of catastrophic wildfires

### Forest Health Aerial Surveys

Every year the US Department of Agriculture's (USDA's) Forest Service conducts an Aerial Detection Survey (ADS) to provide annual estimates of tree mortality and damage and depict broad mortality trends used by the fire mitigation community to detect hazards.<sup>1</sup> CAL FIRE called out the importance of the program both in California and nationally. In California, the ADS is conducted via aircraft once a year. Although the program in California is relatively inexpensive and covers the whole state (\$150,000 for the plane, pilot, and two contractors), SBG might allow similar types of information to be collected more frequently and more widely across the country to identify potential fire hazards and threats to valuable ecosystems. SBG was also cited as a potential alternative to reduce the risks/dangers of the flights due to potential crashes and more recent concerns about COVID-19.

# Fire Ecology & Risk—Users Interviewed



## Key Informant

## Organization Type



Tom Rolinski, *Southern California Edison*



Carol Baldwin, *Great Plains Fire Science Exchange*



Krista West, *San Diego State University*



Joaquin Ramirez, *Technosylva, Inc.*



Mikel Robinson, *International Association of Wildland Fire*



Ed Brunson, *Joint Fire Science Program*



Brian D'Agostino and Chris Arends, *San Diego Gas & Electric*



Mark Rosenberg and Tiffany Meyer, *CAL FIRE*



Mark Melvin, *Jones Center at Ichauway*



Jessica McCarty, *Assistant Professor, Miami University*

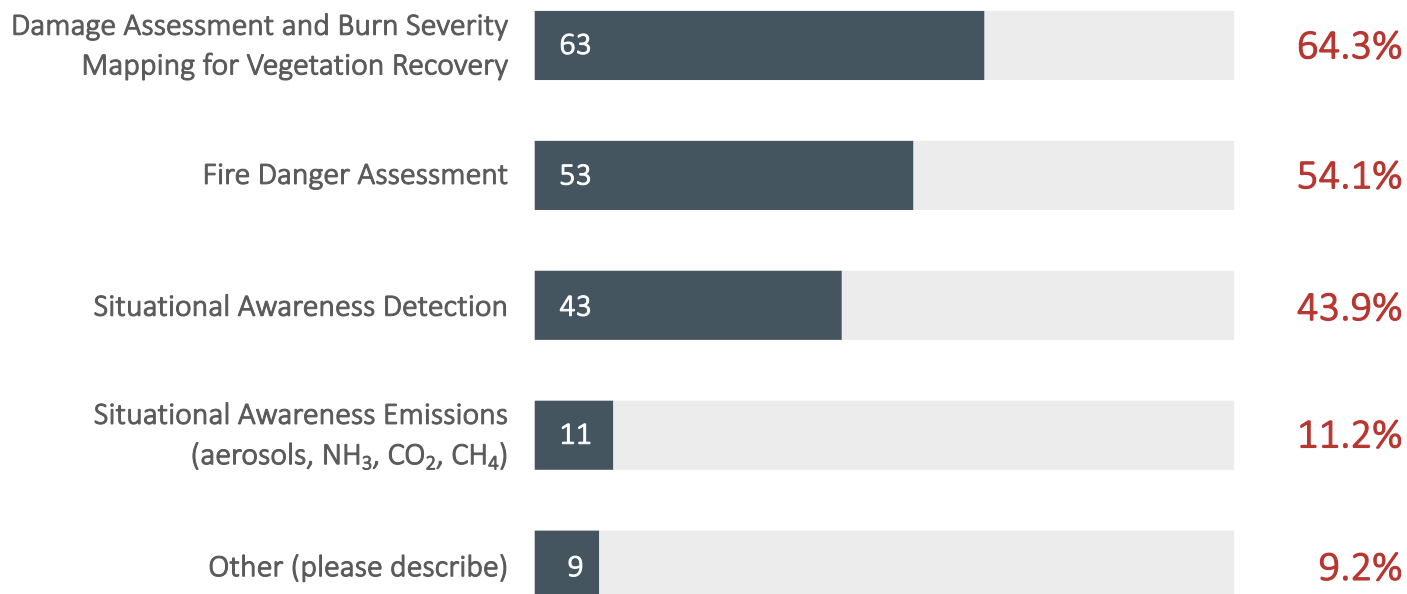


# Fire Ecology and Risk

## Application—Survey Results



The top 2 most important “activities” that your organization is trying to accomplish.



Pre- and post-fire damage assessments are priority activities for those working with remote sensing observation methods. Fire danger assessment was identified as the second most important activity, although fire danger assessment overlaps in many ways with situational awareness activities.

# Fire Ecology and Risk—Survey Results

## Satisfaction with Current EO data, SBG improvement



*To what extent is the current remote sensing and EO data you use adequate for the following purposes? \*Remote sensing refers to the science of identification of Earth surface features and estimation of their geo-biophysical properties using reflected or emitted energy.*

	Not at All Adequate		Slightly Adequate		Moderately Adequate		Very Adequate		Completely Adequate		Re-sponses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	
Avoided damages from forest fires to private property (e.g., houses, automobiles)	11	12.2%	29	32.2%	41	45.6%	5	5.6%	4	4.4%	90
Avoided damages from forest fires to private industry (e.g., lost revenue from forestry or insurance industries)	11	12.4%	22	24.7%	48	53.9%	5	5.6%	3	3.4%	89
Stewardship of public resources for water or drought management for agriculture	4	4.4%	24	26.4%	48	52.7%	12	13.2%	3	3.3%	91

*For your organization's top two most important activities, to what extent could fire risk mapping activities or processes be improved with the SBG platform capabilities?*

	No Improvement		Very Mild Improvement		Mild Improvement		Moderate Improvement		Significant Improvement		Re-sponses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	
Fire danger assessment	0	%	0	%	3	6.8%	20	45.5%	21	47.7%	44
Situational awareness detection	0	%	0	%	3	8.1%	22	59.5%	12	32.4%	37
Situational awareness temperature	0	%	0	%	0	%	0	%	0	%	0
Situational awareness emissions (aerosols, NH <sub>3</sub> , CO <sub>2</sub> , CH <sub>4</sub> )	0	%	0	%	1	10.0%	4	40.0%	5	50.0%	10
Damage assessment and burn severity mapping for vegetation recovery	0	%	1	1.8%	3	5.5%	20	36.4%	31	56.4%	55
Improved forest insurance products	0	%	0	%	0	%	0	%	0	%	0



# Fire Ecology and Risk

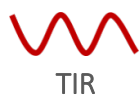
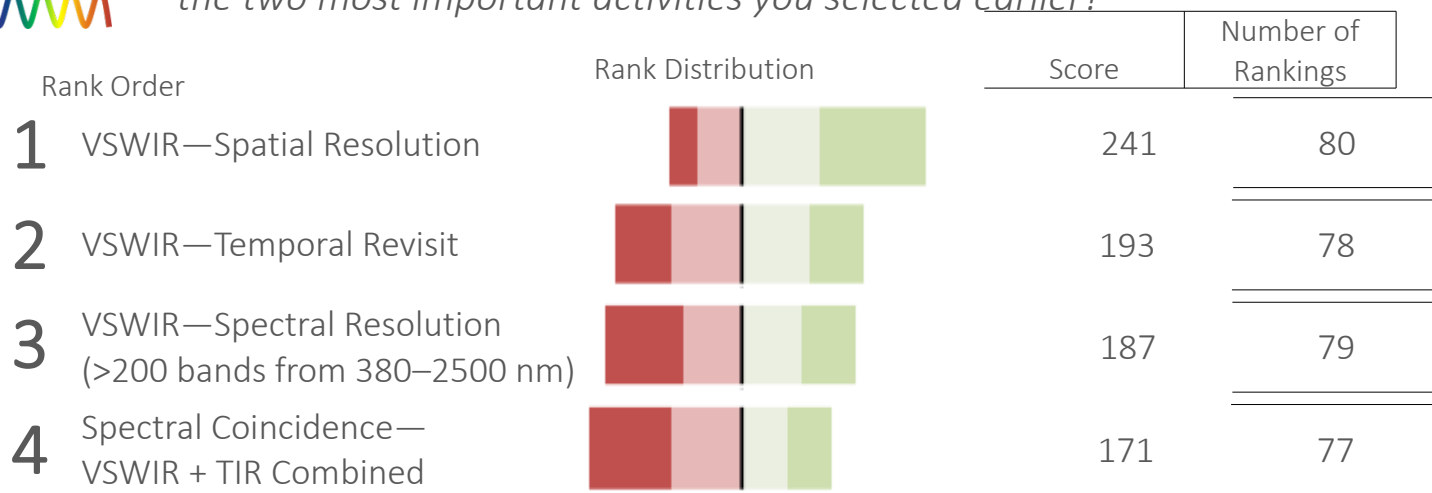
## SBG Capabilities—Survey Results



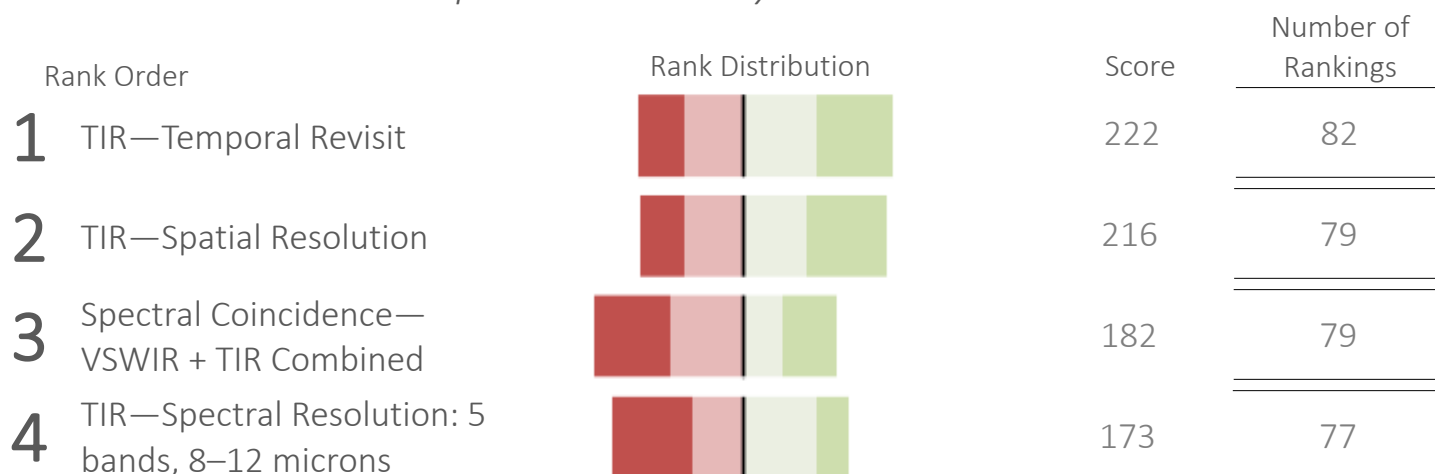
The size of the bar segments in the figures below indicate the number of respondents who ranked each capability #1 (area of right-most segment) to #4 (left-most segment). A weighted average was then used to generate the score and rank order.



Rank Order—Which capability would most improve your ability to do the two most important activities you selected earlier?



Rank Order—Which capability would most improve your ability to do the two most important activities you selected earlier?



The spatial resolution and temporal revisit are SBG's top capabilities, but the consensus on capability rank order is relatively low among the primary applications.

# Fire Ecology and Risk—Survey Results

## Latency and Information Quality Priorities



*For your most important activities, to what degree are the following levels of data latency adequate?*

	Greatly Improves Activities		Adds Some Additional Improvement		Adequate to Accomplish Activities		Minimum Necessary to Accomplish Activities		Inadequate—Cannot Accomplish Activities at this Level		N/A or Unsure		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	
<24 hours	51	58.6%	15	17.2%	7	8.0%	3	3.4%	3	3.4%	8	9.2%	87
<48 hours	20	23.5%	31	36.5%	9	10.6%	5	5.9%	9	10.6%	11	12.9%	85
<1 week	9	10.3%	14	16.1%	30	34.5%	13	14.9%	17	19.5%	4	4.6%	87
<1 month	3	3.5%	5	5.8%	10	11.6%	20	23.3%	39	45.3%	9	10.5%	86
More than 1 month	2	2.4%	1	1.2%	8	9.4%	10	11.8%	54	63.5%	10	11.8%	85

*For the use of Earth observation data in mining, how important are the following information quality and accessibility issues?*

	Not at All Important		Slightly Important		Moderately Important		Very Important		Extremely Important		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	
Cloud-free, usable imagery	0	%	4	4.5%	8	9.1%	34	38.6%	42	47.7%	88
Event Driven	4	4.5%	6	6.8%	26	29.5%	22	25.0%	30	34.1%	88
Data continuity	0	%	3	3.4%	15	17.0%	40	45.5%	30	34.1%	88
Data and data product standardization	2	2.3%	1	1.1%	15	17.0%	41	46.6%	29	33.0%	88
Information cost	6	6.9%	9	10.3%	19	21.8%	25	28.7%	28	32.2%	87

# Agriculture and Water Resources



# Ag/Water Resource—Community Overview

Diverse users envision using SBG data for sophisticated modeling.



## Key Potential Users of SBG

### Data/Products

- Commercial agriculture product input and equipment companies
- Crop consultants and large-farm managers
- Ag conservation and ecosystem market communities and environmentalists
- Agriculture commodities traders and insurers
- Ag/water resource managers and policymakers and local regulatory agencies
- Researchers and data product/service developers



## Key Use Cases of SBG Data/Products

- Agricultural water resources management and drought monitoring
- Crop type, crop composition, crop health monitoring (for ag policies; supply chain; input optimization, e.g., nitrogen, phosphorus, and potassium [NPK])
- Crop residue, cover crop monitoring (for ecosystem services and credits, e.g., MRV)
- National agriculture food security/yield forecasting/management

**There is a growing need for better models.** The diversity of users and applications across the agriculture and water nexus make common drivers hard to identify, but one trend prevails, which is the need for more advanced monitoring and models. Agriculture is shifting to precision farming and improved “right practice at the right place” to increase yields, conserve soil, and develop new ecosystem service offerings. These highly localized practices demand better crop, soil, moisture, and data to enable these new pursuits. Those trying to manage scarce water resources need better models and monitoring to improve forecasting, usage management, and decision-making. However, the typical end user is not an expert in geospatial data sets or advanced models. They look to algorithm and model developers and digital agronomists to make advanced observations usable and actionable.

**Users need precise and timely data.** Current remote sensing and field-level monitoring are often seen as adequate but meeting the future needs of this diverse sector will require not just more advanced tools but advances in science, modeling, and data-driven practices that can be applied locally and scaled broadly. But the data and models must meet practical temporal and spatial resolution requirements of dynamic systems.

**NASA must build communities of potential and practice.** Ag and water users deal with large dynamic ecosystems, complex variables, and numerous stakeholders, so they want practical and applied tools. NASA likely will have to expand support for the evolution of HIS applied science and ongoing model development to an even wider range of agriculture, conservation, and water management demonstration projects. Like other diverse user communities this will require continued and expanded partnering across the many different types of user communities to ensure SBG creates high value.



# Ag/Water Resource—User Needs

SBG may enable precise crop monitoring but not at the desired scale.



Large commercial agriculture companies and model developers see strong potential for SBG's HIS and coincident TIR resolution and view it as a significant improvement over current methods. The high fidelity could substantially improve ET models and the precision monitoring of seasonal trends, crop cover, and ecosystem services. SBG could improve growth and yields by monitoring water, nutrient, and disease stress and enabling growers to do mid-season corrections. The field-scale monitoring can support a variety of MRV programs and improved farm, business, and national-scale food supply management.

Yet the temporal revisits cannot observe most crop growth/moisture dynamics, and <3 days revisits are needed for better ET models. Also 30-m/100-m spatial resolution limits the ability to support industry shifts toward site-specific management and precision and plant-scale farming.

## SBG Capability User Assessment—Ag/Water Resource Mapping

		Priority Applications		
		Crop type, composition, health monitoring	Agricultural water use monitoring	Crop residue, cover crop monitoring
Spectral	VIS-NIR	✓	✓	✓
	SWIR	✓	●	●
	TIR	✓	✓	✓
Spatial	VSWIR (≤30 m)	X	X	●
	TIR (100 m)	X	X	●
Temporal	VSWIR (16 d)	X	X	●
	TIR (3 d)	●	●	●
		Priority – High (H), Med (M), Low (L), Unknown		
Other	Coincidence	H	H	H
	Sensitivity	H	M	M
	Latency	H	H	M
	Global/Large-Area Coverage	M	M	M

### Legend:

- ✓ Is a significant benefit addressing unmet need(s)
- Is an adequate benefit that meets need(s)
- X Does not provide benefit or does not meet need(s)

## Users Capability Priorities (Listed in rough order of importance)

### Temporal:

- High priority. 16 day is inadequate, need <2 days to see growth/stress events in time.
  - Temporal is as important as spectral to monitor crop health, but weekly is adequate for NPK, damage
  - Latency should match need for near-daily monitoring

### Spatial:

- Spatial resolution is inadequate for most crop monitoring.
  - 30 m is only adequate for intra-field/boundary, water rights.
  - Require <5 m for crop-/plant-scale monitoring

### Spectral:

- NIS-VIR and TIR resolution are high priority for composition and stress.
  - SWIR bands nice for soil/disease, but more than needed

### Coincidence:

- Is important for soil moisture and ET data products and complex boundary area mapping.

### Sensitivity:

- Expect sensitivity is more than adequate.

# Ag/Water Resource—User Personas

SBG-derived tools have many users and applications.



## Local Agency

### Ag Water Managers

Water management, particularly in drought-prone areas, is really hard. There are so many stakeholders and so much at stake that making sound policy and real-time decisions is hard.

We are not good at forecasting because we do not have great models, and we have a hard time making trade-offs without the objective information we need. What I need is a single rigorous model everyone agrees on and evidence-based data across the region to guide decision-making. Having these tools would help us a lot.

“I rely on scientists to develop production-ready ET models, so we have defensible decision-making.”

## Commercial User

### Large Agri-Products Co., Digital Agronomist

We need to build our business for low-, middle- and high-income countries. Industrial farms in developed nations can access the best tools and pay for the best inputs. But small holders in developing countries need help too, and it can be good business.

If we can build field-scale maps and models for monitoring crop type, growth, and health, we can advise small holders and build business in new ways. This will improve farming practices and food security in food-challenged regions.

“Digital agronomy is new for our business, but it is the future of business opportunities and improving farming practices.”

## Value-Added Service Provider

### Crop Modeling Developer

Generally, geospatial data are still underused by the agriculture community. But there are so many potential applications; we are just evolving the field. Taking already available data and developing new models and libraries is as important as new HIS.

New data have no value if it is not interpreted or not practically usable. NASA needs to partner with the private sector to make all this data more practical and usable for use in models and tools farmer can actually use.

“60 bands at 5 m, or every 2 days, could be better than 200 bands at 30 m every 2 weeks.”



# Ag/Water Resource—Valuation

## Observations Context and Challenges



Farmers regularly face uncertainty and risk from unpredictable rainfall patterns, highly variable field conditions, and commodity price volatility. To mitigate this risk, farmers often overapply inputs (e.g., seeds, agrochemicals, water) that negatively affect their bottom line and lead to environmental impacts. These impacts include increased greenhouse gas emissions, groundwater contamination, surface water runoff, and downstream water pollution. Because they lack resources, smallholder farmers are less likely to overapply inputs and to contribute to these environmental impacts, but they are even more susceptible to food insecurity.

### How can satellite data help?

One of the key areas that has exploded over the last two decades is precision agriculture, or the ability for farmers to manage their land in a site-specific way. Precision agriculture has led to multibillion-dollar benefits for farmers<sup>1</sup> and provides numerous additional environmental benefits that are more difficult to quantify. There is potential to further increases in the benefits of precision agriculture by large-scale incorporation of remote sensing data.

### Challenges with current EO data products?

Currently, the agricultural sector uses satellites to support precision agriculture in a limited way and for many other nonprecision agriculture uses such as land use mapping, drought identification, and water resource management. The spectral data currently available from freely available satellites enable one to know whether something is growing (e.g., normalized difference vegetation index—NDVI) and can be combined with other data to sometimes distinguish crops, but the data are limited in the ability to provide information on the vegetative composition and water content—both key inputs for making near-term management decisions and doing the predictive yield modeling that is key for medium and longer term planning.



# Ag/Water Resource—Valuation

## Application Impacts



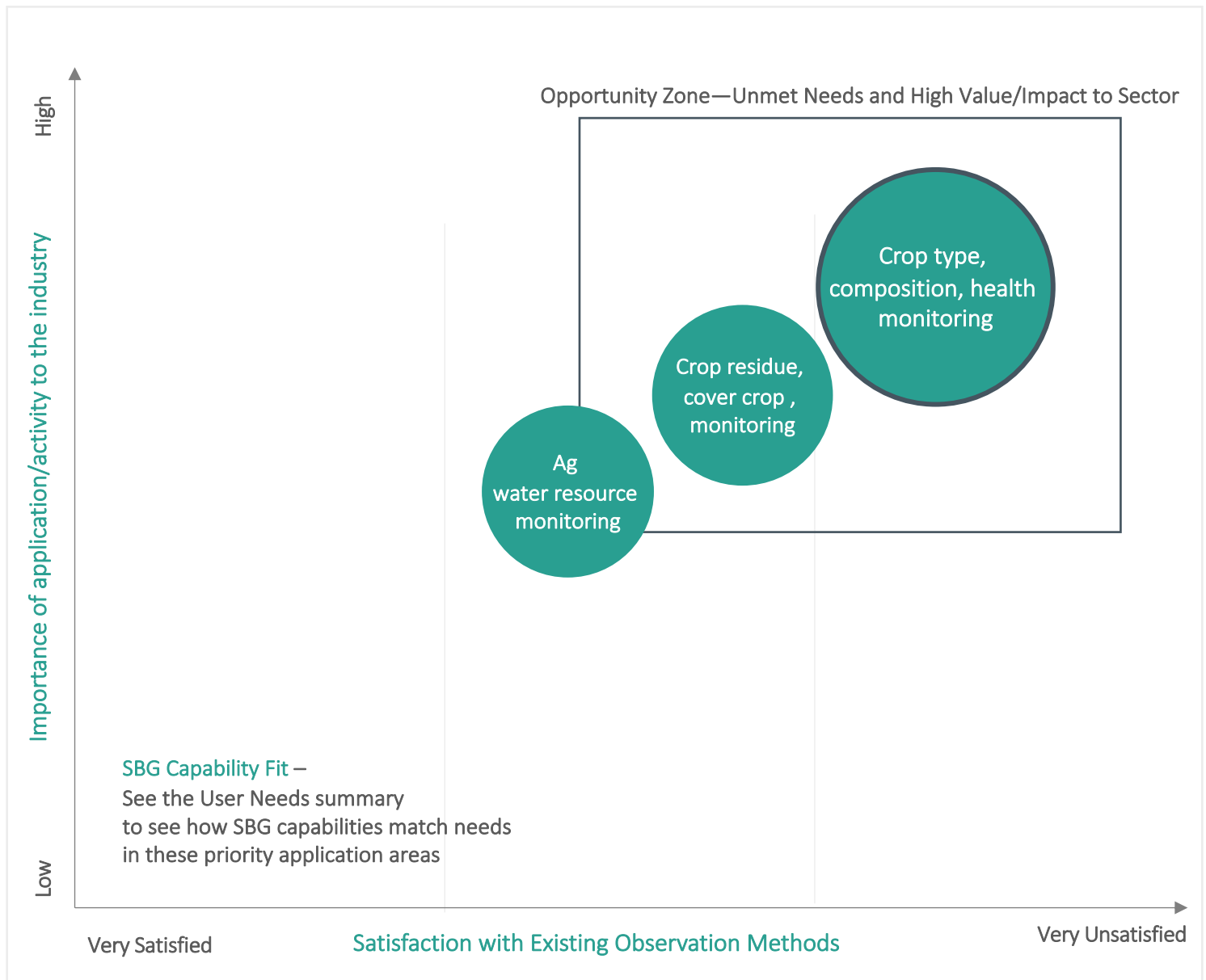
### How can SBG help?

By providing improved hyperspectral VSWIR and thermal data at better spatial resolution and temporal frequency, there are numerous ways that different users in the agricultural sector may be able to benefit (see table below). Within precision agriculture, some of the greatest potential for benefits are through the improvement of VRTs and those that match agricultural inputs to crop needs. Technical experts also believe that SBG would be a game changer for improved mapping of cover crops and soil residue badly needed for unlocking ecosystem services, but these benefits are more difficult to quantify. Experts also believe that SBG could improve water resource management, but challenges include the temporal frequency of the data and would only represent one improved input into complex evaporative stress models.

End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
<b>Commercial/technology-oriented farmers</b>	Hyperspectral data that identify plant composition will provide improvements to precision agriculture in the form of: <ul style="list-style-type: none"> <li>• More precise and dynamic input applications</li> </ul> Thermal data that provide more precise estimates of <ul style="list-style-type: none"> <li>• Data products for water/irrigation management</li> </ul>	Increase net benefits to farmers due to improvements and expansions of precision agriculture adoption and, in particular, variable-rate applications	Increased yields (higher revenues) and reduced input costs due to the ability to more precisely apply inputs and maximize yields throughout the growing season	High
<b>Public sector and NGOs promoting climate change mitigation/ecosystem services</b>	Hyperspectral data would allow for improvements in mapping cover crop type and residue mapping to better target and incentivize conservation practices with multiple ecosystem service benefits	Federal and local governments can better target conservation incentive programs to areas of higher risk  Scale MRV for conservation programs  Remove barriers to scaling ecosystem services in agriculture	Reduced cost or removed barriers to developing verified emission reductions  Value of increasing carbon offsets  Reduced nitrogen and agrochemical pollution	Medium/High
<b>Commercial agricultural companies and crop consultants</b>	Hyperspectral data would allow agricultural input companies to: <ul style="list-style-type: none"> <li>• Optimize their supply chains to farmers' needs</li> <li>• Improve precision agricultural technology offerings to farmers</li> </ul>	Input provision companies can pre-position their representatives to provide advice and sell inputs  Agriculture equipment manufacturers can improve their technological tools and offerings	Reduced supply chain costs (e.g., labor)  Increased sales of agricultural inputs and technology	Medium

# Ag/Water Resource—SBG Opportunity Zone

Areas with High Unmet Needs and Potential Value



Circle size indicates relative value of application.



Crop composition and health monitoring is a key activity and has very large sector impacts. The case study deals with one aspect of crop health management—VRT.

# Ag/Water Resource—Valuation Case Study

For farmers who use VRT, SBG may provide an increase of greater than \$30M annually.



This case study estimates the value that SBG capabilities might provide to farmers who use VRT. This value represents net benefits (e.g., profits) to farmers in the United States, including increases in the value of production (revenue) and reductions in input costs (savings).

## Methods, Existing Resources

Experts pointed to multiple potential benefits from SBG related to VRT, which are summarized in the table on the Valuation—Application Impacts slide, including the ability to:

- Make mid-season nitrogen fertilizer adjustments
- More precisely apply phosphorus
- Optimize combine harvesting and harvest patterns

Experts believe that a conservative estimate of these SBG benefits would result in a 10–20% increase over the current profits that VRT provides to farmers.

## Discussion/Assumptions

The above benefits represent a conservative estimate because it does not include the environmental benefits of a reduction in pollution resulting from applying fewer agrochemicals to the landscape. Also, it critically assumes that the technology needed to convert the satellite data into decision support tools that are integrated into agricultural equipment such as tractors and combines is fully developed.

### Case Study Value of SBG

O'Connor et al. (2019) estimated total annual net benefits from VRT to farmers in the United States to be \$166M in 2017. If we assume a 10–20% increase due to SBG, this amounts to \$17M–\$33M in increased revenue to farmers in that year.

VRT has only been adopted on 5%–38% of major crops in the United States (depending on the crop [O'Connor et al., 2019]). If improved satellite data increased this number by an additional 20%, profits could increase an additional \$33M annually (totaling \$50M–\$66M annually).



# Ag/Water Resource—Valuation

## Additional Valuation Vignettes

### Conservation Management Practices

Leading remote sensing technology service providers said that SBG would be a game changer for the ability to distinguish cover crop types and would allow for improvements in soil residue mapping, which is important for expanding conservation tillage practices. Increasing the adoption of these conservation and regenerative practices would have two important environmental benefits for public and NGO sector end users.

Conservation incentive programs could better target areas of high environmental risk for incentive payments globally (USDA has incentivized more than 10M acres of cover cropping in the US since 2009).<sup>1</sup>

The data could also improve MRV needed for voluntary and compliance carbon and other ecosystem markets in the agricultural sector, lowering the barriers to entry for future carbon markets.

### Water Resource Management/Irrigation Scheduling

Remote sensing has enabled farmers to reduce their water footprint in water-scarce regions.<sup>2</sup> It is possible that SBG could further increase those benefits for lead farmers in the industry, such as E&J Gallo Winery or Driscoll's (with annual sales of approximately \$3B as of 2016).<sup>3</sup> However, experts also speculated that SBG's thermal revisit would need to be 1–2 days to really move the needle in this area.

Experts also thought that SBG would enable the development of greatly improved global irrigation mapping. This tool would enable better irrigation planning and water resource management to bring value to farmers in both low- and high-income contexts.

# Ag/Water Resource—Users Interviewed



## Key Informant

## Organization Type



Molly Brown, 6<sup>th</sup> Grain



Mario Kunz, Syngenta Foundation for Sustainable Agriculture



Jessica McCarty, Miami University



Forrest Melton, OpenET



James Prairie, USBR



Nate Torbick, Applied GeoSolutions



Jane Zelikova, Carbon 180



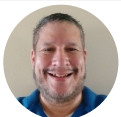
Mark Tracy et al., Cloud Agronomics



Bill Salas, Applied GeoSolutions



Alex Foessel, Independent Consultant (former John Deere)



Tom Mueller, Geospatial Technical Solutions



Kara Stevens, The Walton Family Foundation

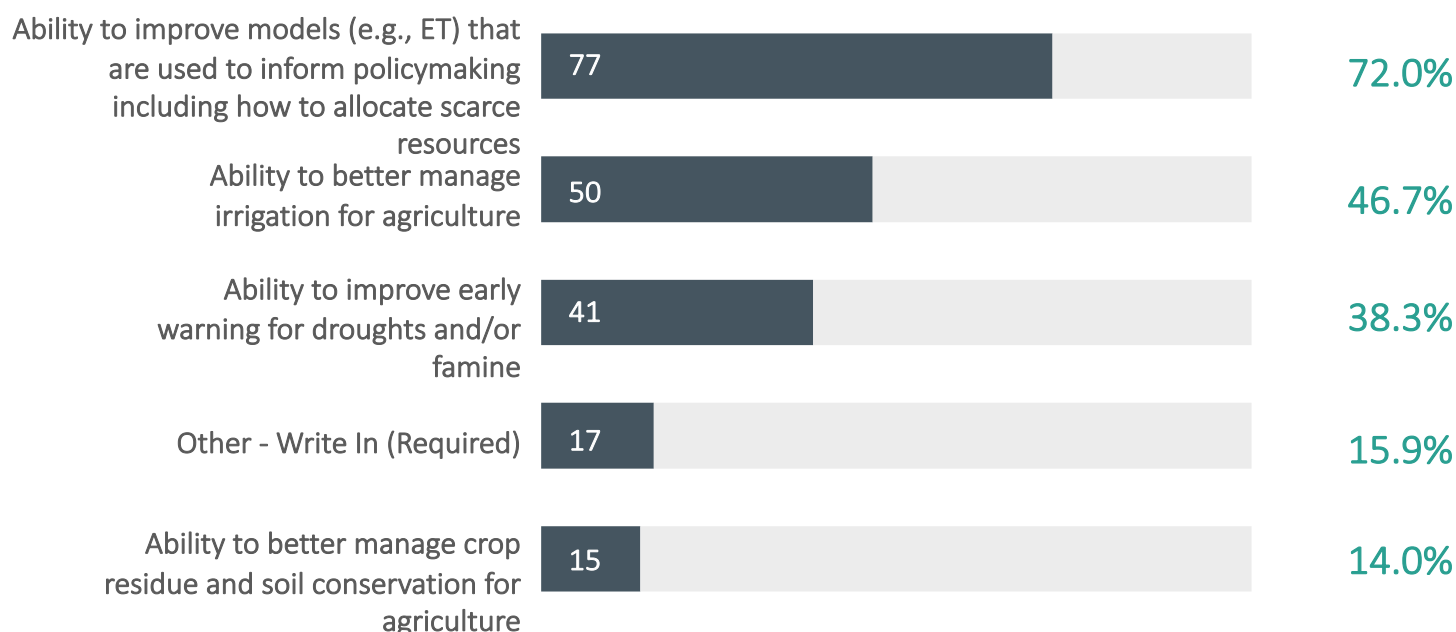


# Ag/Water Resource—Survey Results

## Priority Applications



*When doing agriculture, water, and drought risk management, which of the following are the most important “activities” that your organization is trying to accomplish? Select your top 2 activities.*



Improving data products and models for resource application and decision-making is by far the highest priority application. This result is notable not just because of the margin of relative importance over other activities, but also because the respondent set is the largest and most diverse among the primary application areas. Users spanning supply- and demand-side interests and production and conservation communities showed consensus on this point. A limited set of “other” applications largely aligned with the basic categories already listed.

# Ag/Water Resource—Survey Results

## Satisfaction with Current EO Data, SBG Improvement



*To what extent is the current remote sensing and Earth observation data you use adequate?*

	Not at All Adequate		Slightly Adequate		Moderately Adequate		Very Adequate		Completely Adequate		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Individual farmers, the agricultural industry, and the insurance industry	7	7.3%	35	36.5%	49	51.0%	4	4.2%	1	1.0%	96
Famine early warning and the avoidance of hunger	3	3.9%	16	21.1%	43	56.6%	12	15.8%	2	2.6%	76
Stewardship of public resources for water, soil, or drought management for agriculture	2	1.9%	30	29.1%	60	58.3%	8	7.8%	3	2.9%	103

*For your organization's top two most important activities, to what extent could agriculture, water and drought risk management activities or processes be improved with the SBG platform capabilities?*

	No Improvement		Mild Improvement		Moderate Improvement		Significant Improvement		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Ability to better manage crop residue and soil conservation for agriculture	0	%	0	%	5	41.7%	7	58.3%	12
Ability to better manage irrigation for agriculture	1	2.3%	2	4.5%	14	31.8%	27	61.4%	44
Ability to improve early warning for droughts and/or famine	1	2.7%	3	8.1%	18	48.6%	15	40.5%	37
Ability to improve models (e.g., ET) that are used to inform policymaking including how to allocate scarce resources	1	1.5%	0	%	23	35.4%	41	63.1%	65



# Ag/Water Resource—Survey Results

## Most Desired SBG Capabilities



The size of the bar segments in the figures below indicate the number of respondents who ranked each capability #1 (area of right-most segment) to #4 (left-most segment). A weighted average was then used to generate the score and rank order.



Rank Order—Which capability would most improve your ability to do the two most important activities you selected earlier?

Rank Order	Rank Distribution	Score	Number of Rankings
1 VSWIR—Spatial Resolution		258	87
2 VSWIR—Temporal Revisit		256	88
3 Spectral Coincidence—VSWIR + TIR Combined		190	88
4 VSWIR—Spectral Resolution: (>200 bands from 380–2500 nm)		176	87



Rank Order—Which capability would most improve your ability to do the two most important activities you selected earlier?

Rank Order	Rank Distribution	Score	Number of Rankings
1 TIR—Temporal Revisit		270	91
2 TIR—Spatial Resolution		258	87
3 Spectral Coincidence—VSWIR + TIR Combined		176	84
4 TIR—Spectral Resolution: 5 bands, 8–12 microns		161	82

The spatial resolution and temporal revisit of SBG are effectively equally critical capabilities for the agriculture and water resource user community. It is interesting that given the large and diverse respondent set there is such high consensus across VSWIR and TIR capability rankings.

# Ag/Water Resource—Survey Results

## Latency and Information Quality Priorities



*For your most important activities, to what degree are the following levels of data latency adequate?*

	Greatly Improves Activities		Adds Some Additional Improvement		Adequate to Accomplish Activities		Minimum Necessary to Accomplish Activities		Inadequate - Cannot Accomplish Activities at this Level		N/A or Unsure		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
<24 hours	53	60.2%	16	18.2%	13	14.8%	0	%	0	%	6	6.8%	88
<48 hours	31	34.4%	34	37.8%	19	21.1%	2	2.2%	0	%	4	4.4%	90
<1 week	13	14.8%	14	15.9%	39	44.3%	15	17.0%	5	5.7%	2	2.3%	88
<1 month	8	8.8%	5	5.5%	20	22.0%	24	26.4%	27	29.7%	7	7.7%	91
More than 1 month	3	3.3%	4	4.4%	7	7.8%	21	23.3%	42	46.7%	13	14.4%	90

*For the use of Earth observation data in Ag/drought/crop monitoring, how important are the following information quality and accessibility issues?*

	Not at All Important		Slightly Important		Moderately Important		Very Important		Extremely Important		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Cloud-free, usable imagery	0	%	1	1.0%	6	6.2%	31	32.0%	59	60.8%	97
Event driven	9	9.6%	23	24.5%	30	31.9%	18	19.1%	14	14.9%	94
Data continuity	0	%	2	2.1%	7	7.2%	43	44.3%	45	46.4%	97
Data and data product standardization	2	2.1%	1	1.0%	15	15.5%	47	48.5%	32	33.0%	97
Information cost	2	2.1%	12	12.6%	19	20.0%	31	32.6%	31	32.6%	95

# Algal Blooms and Water Quality



# Algal Blooms/Water Quality—Community Overview

Users are slowly adopting new tools and SBG could help.



## Key Potential Users of SBG Data/Products

- State-level health, environmental, and water quality agencies, inland and coastal
- Public health entities (e.g., hospitals/clinics) and agencies (CDC, NIH, EPA)
- Aquaculture, fisheries, and shellfish organizations and companies
- Drinking water utilities
- Forestry industries and lake management associations
- Water engineering firms and consultants doing applied research



## Key Use Cases of SBG Data/Products

- Wide area monitoring of resolvable and unresolvable lakes, reservoirs, and rivers
- Early warning modeling and maps of HABs, mapping of “susceptible water”
- Monitoring and mapping of water chemistry to help locate, guide growth/health of shellfish
- Monitoring of upstream/downstream point-source pollution, nutrient flows, runoff
- Wastewater and watershed management

**Overall, the sector is an SBG community of potential.** This study’s focus on algal blooms gathered the needs of inland and coastal user communities, but SBG can provide great benefit for many other current and potential water quality relevant applications. However, entrenched water quality monitoring and industry methods, combined with limited resources and incentives, mean the sector’s focus is often limited to meeting basic safety standards. Currently, only selected groups of researchers and early adopters understand the potential for HIS. Programs like CyAN are building awareness, but this sector will require a lot more engagement and support for SBG to be widely leveraged, particularly for commercial users.

**There is great potential to help with large-area monitoring.** Water quality and environmental health stakeholders cannot monitor their entire jurisdictions effectively, leaving significant inland and coastal waters unobserved. The coverage and additional resolution of SBG would improve the scale of useful monitoring by orders of magnitude for time-series studies of susceptible water. Yet the dynamic nature of bloom and coastal systems means SBG is inadequate for the most important user activities identified.

**Researchers are hopeful but not convinced that SBG can truly provide the algal composition and validated water chemistry and particulate monitoring they desire.** NASA likely will have to support the evolution of HIS-applied science and demonstration projects. Ground truthing and in-field sampling are under-resourced but required to meet standards, so NASA may also have to consider ways to fund, ensure, and integrate observation methods in conjunction with SBG to truly enable its utility and adoption. This will likely require continued and expanded partnering across the many different type of water management communities to bring value to users.



# Algal Blooms/Water Quality—User Needs

Global, HIS coverage at <30 m is an unmet need.



For remote sensing and algal bloom mapping experts, the HIS in the VIS-NIR is a “game changer, offering orders of magnitude” better HAB composition and concentration data. In practical terms, the global coverage of SBG means monitoring 1000s of currently unresolvable lakes. Point-source monitoring also requires at least 30-m spatial resolution.

However, the temporal revisit rate is not adequate for the dynamic nature and public health risks involved with HABs. One- to 3-day monitoring and 24- to 48-hour latency are driving requirements. For emerging applications in coastal and inland water quality monitoring and aquaculture siting, high SNR SWIR and coincident TIR and better spatial resolution become important.

## SBG Capability User Assessment—Algal Bloom/Water Quality

		Priority Applications			Emerging
		Wide area inland/coastal HAB health monitoring	Utility water HAB warning and intake management	Pollution/nutrient flow at boundaries	Aquaculture farm siting/monitoring
Spectral	VIS-NIR	✓	✓	✓	✓
	SWIR	●	✓	●	✓
	TIR	✓	✓	✓	●
Spatial	VSWIR (≤30 m)	●	●	●	●
	TIR (100 m)	●	●	●	X
Temporal	VSWIR (16 d)	X	X	●	●
	TIR (3 d)	X	X	●	●
Priority – High (H), Med (M), Low (L), Unknown					
Other	Coincidence	M	M	H	L
	Sensitivity	M	H	M	H
	Latency	H	H	H	H
	Global/Large-Area Coverage	H	H	H	L

**Legend:**

- ✓ Is a significant benefit addressing unmet need(s)
- Is an adequate benefit that meets need(s)
- X Does not provide benefit or does not meet need(s)

### Users Capability Priorities

(Listed in rough order of importance)

#### Spectral:

- VIS-NIR and TIR spectral range and hyperspectral resolution are co-top priorities.
  - Only a few SWIR bands needed for basic monitoring, but high SNR SWIR for detailed water chemistry

#### Spatial:

- Global hyperspectral and TIR coverage are key benefits of SBG for wide area monitoring.
- Spatial resolution of 30 m is adequate.

#### Temporal:

- 16 day is inadequate, need almost daily.
  - Temporal is as important as spectral, but with HIS may be able to get some temporal leeway.
  - Latency should match need for near-daily monitoring.

#### Coincidence:

- Is “helpful” but would exchange for better temporal coverage.

# Algal Blooms/Water Quality—User Personas

A few early adopters are trying to bring HIS to the water sector.



## Local Agency

### State Water Officials

The bays and coastlines are huge, and there are too many inland waters to keep track of. Underfunded and without a lot support for trying new technologies it is hard to advance the use of satellite data but there is potential.

There is no way to test everywhere in the field, so better targeting of when and where to test would save a lot of time and help keep people healthy; that is the number one priority. Water quality monitoring is stuck with old methods, so more than glad to partner with NASA, if they can help.

“Public health is job #1, protecting industry is job #2. But I need help.”

## Commercial User

### Shellfish Farm Owner

The shellfish industry is making a paradigm shift from traditional harvesting to industrial farming. To make the ocean the new breadbasket for society, shellfish companies need better remote sensing and modeling tools.

Only a few shellfish farmers really understand what the science and potential for HIS is all about, but it could be part of what revolutionizes how we farm and create a lot of new business. It is the future, and NASA can help build the tools.

“Monitoring for HABS is great, but not much you can do about them. But finding new sites for high-growth shellfish farms will create a new industry.”

## Value-Added Service Provider

### Algal Bloom Mapping Service Provider

It has been a long time coming, but CyAN and commercial tools for algal mapping and modeling are just starting to get attention beyond researchers. But there is huge potential for HIS to be a game changer for water quality monitoring.

What is needed are reliable operational level missions that are not just research experiments. Industry needs to be able to count on high-quality reliable NASA data products; then we can develop the tools people need.

“There have been other HIS research efforts. We need operational missions we can count on.”



# Algal Blooms/Water Quality—Valuation

## Observations Context and Challenges



It is estimated that HABs cost the US economy on average \$50 million per year in health impacts and lost revenues.<sup>1</sup> The majority of this loss is associated with public health, commercial fishing/aquaculture, and recreation/tourism. In addition, case studies have shown algal blooms have significant negative impacts on local property values.

### How can satellite data help?

Although the use of SBG would not eliminate HABs, it would help identify and track them, potentially mitigating some of their impact. For example, advanced warning for beaches and water recreation areas could have significant human health implications from reducing HAB-related illnesses. In one study, conducted by the VALUABLE project<sup>2</sup> to quantify the economic impact of using satellite data for early warning of HABs on lake Utah, researchers found that using satellite data in conjunction with in situ water testing could reduce posting area closure times by 1 week, thus reducing illnesses and avoiding \$368,000 per year in costs due to tracking health outcomes for this single lake.

Other impacts are wide ranging and include reduced fishery and port closure times because of tracking airborne toxins from HABs, cost savings for commercial and recreational fishing and charter boats (fuel and time to find bloom-free areas), and water quality issues that affect livestock.

### Challenges with current EO data products?

Limited spectrum and poor spatial resolution make current EO data of marginal use for complex coastal areas, providing virtually no usable coverage for small- to medium-size lakes, rivers, and streams. In addition, blooms are likely worsening over time. However, there is little time-series data to support this analysis, such as where blooms are shifting to and how a warming climate could affect Total Maximum Load (TML) regulations.



# Algal Blooms/Water Quality—Valuation

University and industry experts identified a range of applications for which SBG would have positive economic impacts.

Algal blooms involve a wide range of user communities that conduct different end uses, so the associated value of SBG will have different magnitudes.

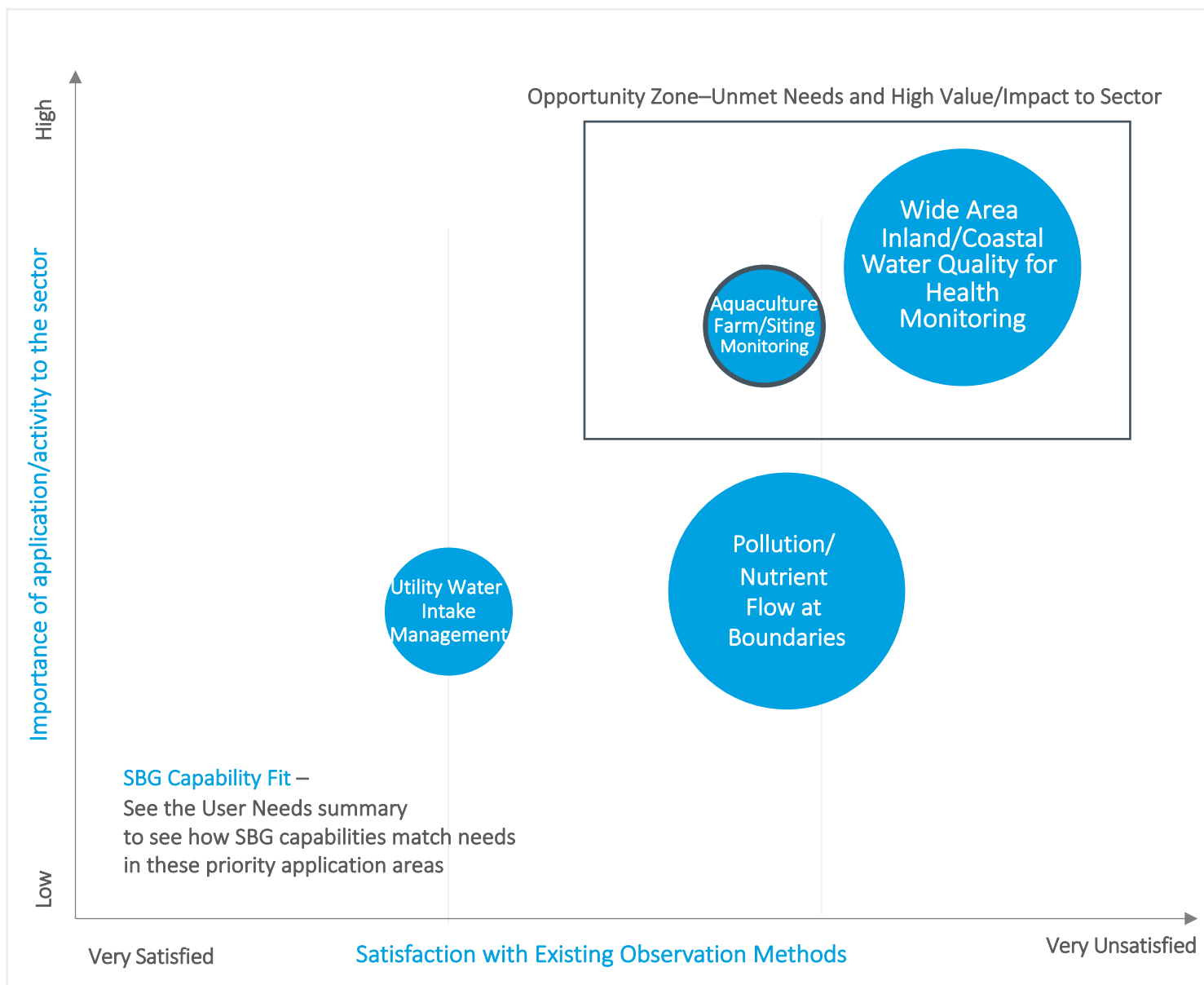
In general, the hyperspectral, spatial resolution, and thermal capabilities provided by SBG would most enhance coastal and large lake remote monitoring of HABs and general water quality. In addition, it would enable remote monitoring of small- to medium-size lakes and rivers, which would improve land use nutrient management policies and enforcement. Currently, only a fraction of lakes across the country are being tested. SBG would provide a screening tool with the spatial resolution to cover 10s of 1000s of lakes, making in situ testing more targeted and productive.

For this study, we focused on the impact areas presented in the table below. The table provides a high-level summary of how SBG could generate benefits and value for these activities in the algal bloom and water management domains.

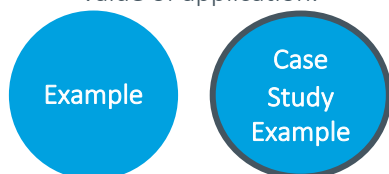
End-User Community	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Local Municipalities and State/Local Health Authorities	Better forecasting and early detection of blooms	Reduced time to public notification	Reduced health care costs	High
	Improved identification of HAB species/colonies	Fewer illnesses and death	Social value of morbidity	
Shellfish Farms	Better detection of water temperature and food sources for optimal siting of farms	Increased productivity/yield of farms	Increased production Increased financing for industry growth	Modest
Salmon Farms	Better detection of water temperature for siting in areas with lowest probability of a super chill event	Reduced fish loss from a super chill event	Increased production Increased financing for industry growth	Modest
Water Utilities	Managing intake and treatment systems when blooms approach	Optimal timing of switching between multiple water intake sources	Reduced operating costs and need for chemicals	Low
Policymakers and Land-Use Monitoring Organizations	Development, monitoring, and enforcement of land-use policies to reduce nutrient run off into streams and lakes <ul style="list-style-type: none"> <li>Monitoring of vegetation and riparian buffers</li> <li>Monitoring agricultural and livestock activities adjacent to water resources</li> </ul>	Reduced nutrient runoff into streams and lakes Reduced algal blooms in streams and lakes Reduced algal blooms in coastal areas fed by these streams/rivers	Less economic loss due to fewer HABs <ul style="list-style-type: none"> <li>Tourism</li> <li>Property values</li> <li>Aquaculture productivity</li> <li>Human health impacts</li> </ul>	High

# Algal Blooms/Water Quality—SBG Opportunity Zone

Areas with High Unmet Needs and Potential Value



Circle size indicates relative value of application.



Wide area HAB and water quality monitoring could have significant health impacts but at this time are difficult to value. Aquaculture's social value may be less but was selected for the case study that follows because its value is clear and could be quantified.

# Algal Blooms/Water Quality—Valuation Case Study

SBG may have a value of >\$700M in annual benefits to the US shellfish industry.

## Improved Site Selection Can Increase Productivity/Yield

Siting for proper environmental conditions can have a huge impact on shellfish farm productivity. Depending on the site characteristics, the time to harvest/market can range from 1 year to 6 years. SBG hyperspectral and greater resolution will provide detailed data that can be used to screen for temperature, chlorophyll, and turbidity—all of which are key drivers of shellfish growth rates.

Currently, some satellite data are used in siting analysis, but because of the low spatial resolution and limited spectral bands, it is only marginally effective, and most measurements for analysis are generated by physical monitoring equipment, which is costly and limits the practical coverage area.

The use of SBG and better algorithms for wide-scale screening of key environmental attributes that drive growth has the potential to increase average productivity by 200% because of better siting of shellfish farms. This impact would be applicable for all three major shellfish types (mussels, oysters, scallops) and would be applicable for northern, middle, and southern regions, as well as on both the East and West Coast.

This additional productivity due to SBG data has the potential to increase industry growth by 10% annually by attracting new investment. Industry operating costs could also be reduced in the range of 5% because of reducing length of closures for fishing areas, better management of harvesting schedules, and quality issues that include lost produce and avoided consumer illnesses.

### Case Study Value of SBG

**US Shellfish Industry Size:** 325 million (2017)<sup>1</sup>

**Value of Improved Siting (200% increase in productivity):** \$650M/year at current industry size

**Industry Growth (additional 10% growth due to SBG over 10 years):** \$65M incremental growth per year (above current growth projections)

**Value of 5% Operating Cost Reductions:** \$16M/year at current industry size

# Algal Blooms/Water Quality—Valuation

## Additional Valuation Vignettes



### Expanding Aquaculture to Deeper Offshore Regions

Aquaculture has the potential to be a significant economic growth area in the future if the oceans can become the next “breadbasket” to feed the world's population. Currently in the US, commercial aquaculture mostly includes shellfish, salmon, and kelp farms, but there is growth potential for many other species, such as tuna.

Most of these farms are currently sited near coastal regions where access and monitoring are easy and suitable sites have been identified over the years by trial and error of aquaculture farming experiments. SBG could help grow the industry by providing information that would help open offshore regions to the industry where there is currently little data or it is too costly to monitor effectively. Being able to characterize areas farther from the coastline for phytoplankton, temperature, and HABs, for both siting and ongoing operations monitoring, would make offshore aquaculture farm investments in these areas more attractive.

In 2019, Canada's Cooke salmon farm lost about 10,000 Atlantic salmon at its Kelly Cove salmon site off the coast of Coffin Island in Nova Scotia because of a super chill event. The water temperatures in Atlantic Canada dropped to  $-0.7$  degrees Celsius ( $30.74$  degrees Fahrenheit) that causes salmon to freeze. Better data for siting farms could help minimize these events. (Aquaculture Water Quality Expert, University of Maine)

# Algal Blooms/Water Quality—Valuation

## Additional Valuation Vignettes



### Human Health Impacts from Open Water Recreational Activities

SBG would support more comprehensive monitoring of open water recreational areas for HABs and microbial detection leading to water-borne illnesses.

For example, Oregon's Department of Health said they are currently only able to test about 40 of their ~400 lakes in the state. Similarly, the State of Maine said they also are able to test only a fraction of their ~4,000 lakes and many rivers and reservoirs.

Current publicly available satellite data (e.g., Sentinel) do not have the coverage or resolution needed. But with the global coverage and 30-m spatial resolution of SBG states could screen all most lakes and rivers and deploy in situ testing only where HABs are most likely to develop. The HIS capability would enable much more detailed water quality monitoring. Many rivers are used locally for drinking water in small cities and municipalities, so they play a critical role in water supplies.

Over a 10-year period, from 2008 to 2017, the CDC reported 743 water-borne outbreaks, which led to 15,429 illnesses, 1,531 hospitalizations, and 144 deaths. Approximately, 25% of these outbreaks were in nontreated open water (ocean, lakes, streams).

$25\% \times 15,429 = 3,857$  illnesses  $\times \$10,000/\text{illness} = \$38.6\text{M}$  over the 10-year period.

Using the value of a statistical life used by USEPA in economic analyses of environmental regulations of approximately \$6M per death yields \$216M over the 10-year period.

Note—SBG will not eliminate all illnesses or deaths from open water-borne illnesses. However, experts thought that more comprehensive screening and early warning should be able to reduce them significantly.

# Algal Blooms/Water Quality—Valuation

## Additional Valuation Vignettes



### Land Use and Nutrient Management Policy

SBG capabilities will improve monitoring and screening of smaller streams and lakes and the vegetation surrounding them (e.g., riparian buffers). This ability for wide-area screening will make in situ testing resources more efficient and effective because they can be targeted to waterways/bodies with potential issues, greatly benefitting local municipalities and lake associations.

Development and enforcement of watershed management policies can be more evidence based and comprehensive, which is expected to reduce pollution, HABs, and other watershed issues in both inland and coastal areas. Enhanced evidence-based and time series monitoring could be used to support nutrient trading programs and verify conservation credit programs such as those currently used in the Chesapeake Bay.

**Property values:** Studies have shown that reoccurring algal blooms have measurable impacts on waterfront property values. Lakeshore homeowners in multiple states have reported anecdotal evidence of significant declines in their property values, potentially ranging from a 30% to 50% drop in value as a result of HAB events.<sup>1</sup>

Economic studies indicate that if algal blooms could be reduced on Lake Erie, those households within 20 m (66 ft) of the lake could collectively avoid property value declines of \$686M.<sup>2</sup>

Experts envision that over time SBG could not only help mitigate HABs, but also help support land use management monitoring, enforcement, and policies. Improved and evidence-based watershed management could, in turn, help reduce pollution and nutrient runoff, which would then reduce the frequency and severity of blooms, thereby helping to restore property values.

# Algal Blooms/Water Quality—Valuation

## Additional Valuation Vignettes



### Water Municipality Operations

HABs are a constant concern for many local water municipalities and have the potential to significantly affect both public health and operating costs. This has been shown in several high-profile events, such as the 2014 Toledo drinking water ban.<sup>1</sup>

Currently, almost no small- to moderate-size water treatment plants use satellite data. They do not have the staff expertise to process the data for real-time use.

Even larger plants have only modestly integrated the use of remote sensing and EO data into their daily planning and operations. They mostly rely on testing and visual inspections to manage intake operations. Hyperspectral, better spatial resolution, and temperature information would make SBG data much more attractive. But temporal revisits of greater than a few days would still substantially limit the value of SBG in day-to-day operations.

In 2014, Toledo, Ohio, officials issued a 2-ban on drinking and cooking with tap water for more than 400,000 residents because of toxin concentrations that exceeded the World Health Organization guideline level for safe drinking water. The economic impacts of this HAB event have been estimated at over \$65M.



# Algal Blooms/Water Quality—Users Interviewed

## Key Informant

## Organization Type



Yusuke Kuwayama, *Resources for the Future*



Aaron Borisenko and Daniel Sobota, *Oregon DEQ*



Chuanmin Hu, *USF*



Josh Weiss, *Hazen and Sawyer*



Mike Papenfus, *EPA/CyAN*



Emmanuel Boss, *UMaine*



Damian Brady, *UMaine*



Carter Newell, *Undine Marine LLC and Pemaquid Oyster Co.*



John McKay, *Maryland Dept. of Environment*



Matt Hunter, *Oregon State Wildlife Fish and Game*



Katherine Foreman and Karen Wirth, *EPA Algal Blooms*

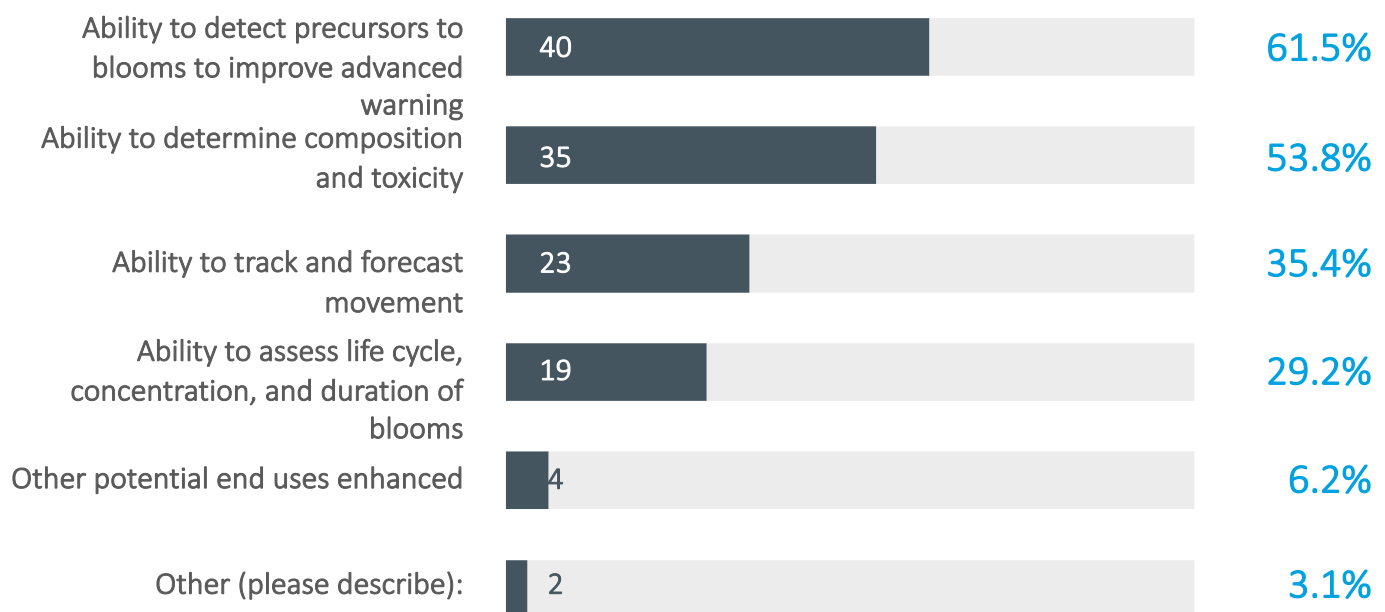


# Algal Blooms/Water Quality—Survey Results

## Priority Applications



*When doing algal bloom work, which of the following are the most important “activities” that your organization is trying to accomplish? Select your top 2 activities.*



The ability to predict and identify algal blooms, for both inland and coastal waters, were the top priorities, but all phases of algal bloom monitoring show up as key activities. Open-ended answers also suggest other water quality monitoring activities are important to the diverse set of respondents for this primary application area.

# Algal Blooms/Water Quality—Survey Results

## Satisfaction with Current EO Data, SBG Improvement



*To what extent is the current remote sensing and Earth observation data you use in the following regions adequate for tracking and analyzing algal blooms?*

	Not at All Adequate		Slightly Adequate		Moderately Adequate		Very Adequate		Completely Adequate		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Coastal regions	5	8.9%	17	30.4%	28	50.0%	4	7.1%	2	3.6%	56
Estuaries and rivers	17	27.4%	26	41.9%	15	24.2%	3	4.8%	1	1.6%	62
Lakes and reservoirs	14	20.9%	30	44.8%	18	26.9%	4	6.0%	1	1.5%	67

Coastal users view current remote sensing and EO data as moderately adequate for their uses. But temporal and spatial resolution limited their potential usefulness for many applications. For smaller inland waters, current remote sensing and EO data do not have the spatial resolution and were viewed as slightly adequate or not adequate at all.

*For your organization's top two most important activities, to what extent could algal blooming activities or processes be improved with the SBG platform capabilities?*

	No Improvement		Mild Improvement		Moderate Improvement		Significant Improvement		Re-
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	sponses
Ability to detect precursors to blooms to improve advanced warning	1	2.9%	1	2.9%	11	32.4%	21	61.8%	34
Ability to determine composition and toxicity	1	3.1%	2	6.3%	8	25.0%	21	65.6%	32
Ability to track and forecast movement	0	%	1	5.6%	7	38.9%	10	55.6%	18
Ability to assess life cycle, concentration, and duration of blooms	0	%	0	%	4	28.6%	10	71.4%	14
Other potential end uses enhanced	1	33.3%	0	%	2	66.7%	0	%	3

# Algal Blooms/Water Quality—Survey Results

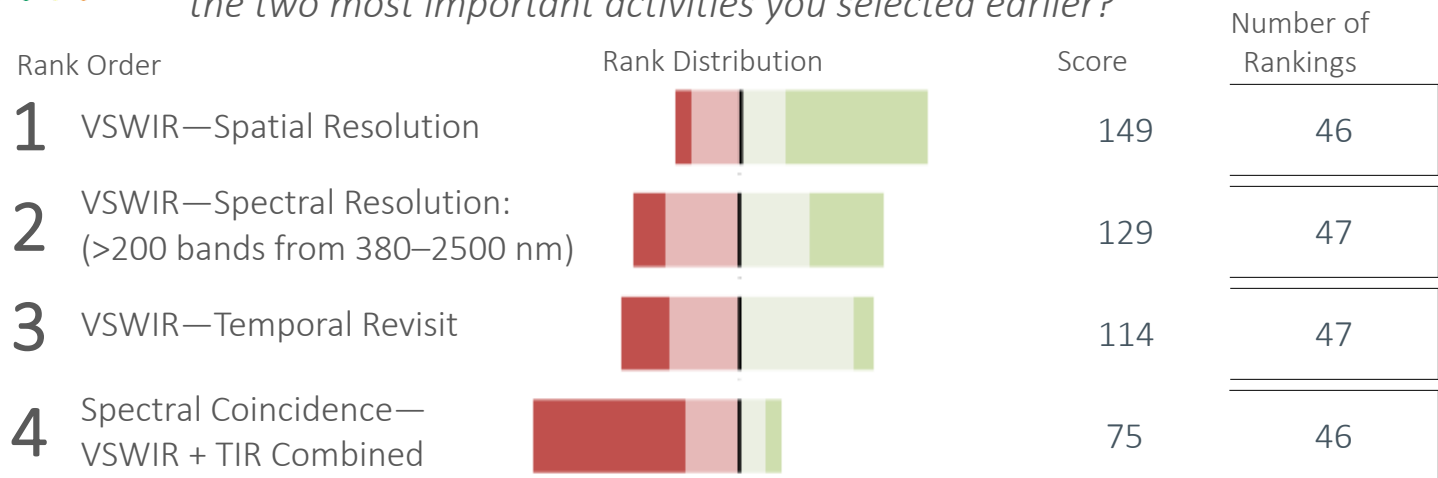
## Most Desired SBG Capabilities



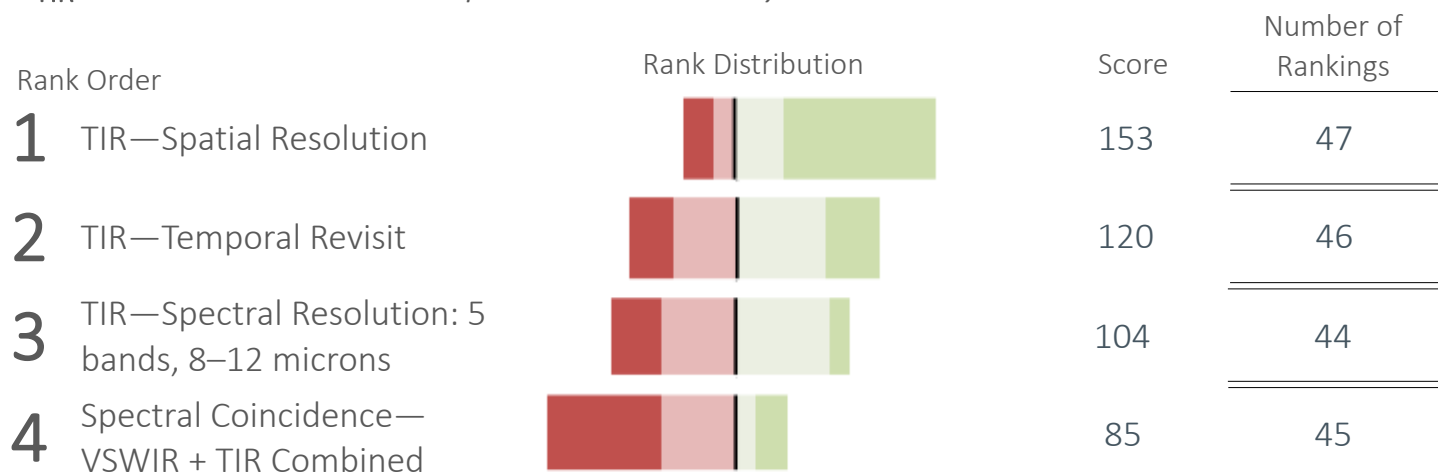
The size of the bar segments in the figures below indicate the number of respondents who ranked each capability #1 (area of right-most segment) to #4 (left-most segment). A weighted average was then used to generate the score and rank order.



Rank order—Which capability would most improve your ability to do the two most important activities you selected earlier?



Rank order—Which capability would most improve your ability to do the two most important activities you selected earlier?



Interestingly, spatial resolution, not spectral, is the most important capability for this small group of algal bloom and water quality mapping respondents.

The number of respondents who answered questions about the algal bloom application area was much lower than the number of respondents who answered questions about the other primary application areas. The specificity of the topic may have limited responses.

# Algal Blooms/Water Quality—Survey Results

## Latency and Information Quality Priorities



*For your most important activities, to what degree are the following levels of data latency adequate?*

	Greatly improves activities		Adds some additional improvement		Adequate to accomplish activities		Minimum necessary to accomplish activities		Inadequate - cannot accomplish activities at this level		N/A or Unsure		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
< 24 hours	38	76.0%	7	14.0%	2	4.0%	1	2.0%	1	2.0%	1	2.0%	50
< 48 hours	14	28.6%	20	40.8%	9	18.4%	4	8.2%	1	2.0%	1	2.0%	49
< 1 week	2	4.0%	12	24.0%	12	24.0%	17	34.0%	6	12.0%	1	2.0%	50
< 1 month	2	4.0%	1	2.0%	2	4.0%	13	26.0%	30	60.0%	2	4.0%	50
More than one month	2	4.1%	0	%	0	%	7	14.3%	34	69.4%	6	12.2%	49

*For the use of Earth observation data in algal blooms/water quality, how important are the following information quality and accessibility issues?*

	Not at All Important		Slightly Important		Moderately Important		Very Important		Extremely Important		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Cloud-free, usable imagery	1	1.9%	0	%	2	3.8%	18	34.6%	31	59.6%	52
Event driven	0	%	5	10.0%	15	30.0%	17	34.0%	13	26.0%	50
Data continuity	0	%	3	6.1%	6	12.2%	29	59.2%	11	22.4%	49
Data and data product standardization	0	%	2	4.0%	14	28.0%	20	40.0%	14	28.0%	50
Information cost	1	2.0%	4	8.0%	10	20.0%	20	40.0%	15	30.0%	50

# Mineral Resources



# Mineral Resources—Community Overview

Spectral geologists skilled in advanced digital tools are looking for the next generation of observation platforms.



## Key Potential SBG Users

- Large mining companies with “spectral geologists”
- Exploration consultants serving “junior” mining companies
- Regulatory and compliance monitoring organizations
- Hyperspectral researchers advancing applications for the energy and mineral resources sector
- VASPs serving the energy and mineral resources sectors



## Key Use Cases of SBG Data/Products

- Studying large geologic processes
- “Greenfield” surveys of large areas
- Revisiting greenfield areas for alterations and previously hard-to-discern minerals
- “Brownfield” discovery of subtle deposits, alterations, and coincident vegetation
- Geobotany—Mineral/vegetation surveys
- Mine site opening baseline mapping
- Operational ore pile and tailing studies
- Environmental/health monitoring on-site and in surrounding environs

**An industry shift will demand more advanced technology.** The mining sector is an early adopter of HIS but has struggled to promote its widespread adoption, seeing remote sensing research efforts come and go. But now the industry is experiencing a pivot, as exploration of “greenfield” opportunities diminish and “brownfield” deposits require better remote exploration techniques. Science and technology must evolve to sustain the industry. At the same time, a new generation of spectral geologists skilled in advanced digital tools is looking for the next generation of observation platforms.

Current spectral imaging solutions are “good enough” for the mining applications of today. But future exploration and more operational and environmental applications will increase in importance and will need to be addressed at scale. The industry will seek step changes in capabilities, and SBG could bring this kind of step change with HIS and high SNR capabilities that will enable broader use or new applications in this sector if priority exploration needs are met.

**A well-funded community of practice that could use SBG now.** Mining companies are well resourced and have a lot invested in remote sensing already and will continue to invest in exploration technologies. This sector has strong trade associations and active communities actively promoting ASTER and EnMAP, so it is a well-connected global community to engage now and for future adoption of SBG products.

**Experts anticipate complexity but want “operational” platforms.** Among seasoned spectral geologists, there is some concern about the complexity of huge SBG data sets and “spectral mixing” at such narrow VSWIR bands. So NASA will have to support the evolution of HIS-applied science, data processing, large data access, analytics platforms, and visualizations to help build usability. Ensuring a long operational mission, quality of data, and ease of adoption of HIS data products will be a critical role NASA must take on, otherwise SBG may be seen as “just another research platform” that did not live up to expectations.





# Mineral Resources—User Needs Summary

SWIR and high SNR are key unmet needs.



For the deep domain experts in this sector, the potential for highly sensitive, high SNR HIS in the VIS-NIR and especially in the SWIR is considered a game changer. If realized, SBG will enable subtle mineral deposits (e.g., rare earth elements and battery metals) exploration and operational monitoring that require higher fidelity than currently available. The additional TIR bands also enable enhanced applications.

However, the current 30-m/100-m spatial resolution is not adequate for the mining industry's top priority exploration needs. Users indicate that VSWIR resolution of 10 m or better is necessary for brownfield and emerging applications. SBG's full potential will not be realized for this sector without better spatial resolution. Experts would trade spectral for spatial resolution.

## SBG Capability User Assessment—Mineral Resource Mapping

		Priority Applications		Emerging Applications	
		Regional Exploration	Local/Site Exploration	Geobotany Mineral/Veg	Site Monitoring, Environmental
Spectral	VIS-NIR	✓	✓	✓	✓
	SWIR	✓	✓	✓	✓
	TIR	✓	✓	✓	✓
Spatial	VSWIR (30 m)	●	✗	✗	✗
	TIR (100 m)	●	✗	✗	✗
Temporal	VSWIR (16 d)	●	●	●	●
	TIR (3 d)	●	●	●	●
Priority – High (H), Med (M), Low (L), Unknown					
Other	Coincidence	M	M	H	H
	Sensitivity	H	H	H	H
	Latency	L	L	L	M
	Global/Large-Area Coverage	H	M	M	H

### Legend:

- ✓ Is a significant benefit addressing unmet need(s)
- Is an adequate benefit that meets need(s)
- ✗ Does not provide benefit or does not meet need(s)

### Users Capability Priorities

(Listed in rough order of importance)

#### Spectral:

- VIS-NIR and SWIR spectral range and hyperspectral resolution are the highest priority.
  - Particularly adding the SWIR bands, which are a primary unmet need

#### Sensitivity:

- High (>100) SNR in VIS-NIR and SWIR bands is critical and essential.
  - >400 VIS-NIR, >250 SWIR is much more than adequate

#### Spatial:

- Global hyperspectral and TIR coverage is key benefit of SBG.
- But spatial resolution of 30 m is inadequate. Require <10 m for key brownfield and emerging applications.
  - 30 m is adequate only for very large regional/nation-scale surveys

#### Coincidence:

- Nice to have for exploration, but important for emerging applications

#### Temporal:

- Revisit of VSWIR and TIR are both more than adequate and are lowest priority. As such, latency is also not a priority.

# Mineral Resources—User Personas

A small community of expert users is excited about SBG.



## Applied Researcher

### Researchers improving mining

Tied into a variety of remote sensing and research communities, they see how new missions can enable new industry AND societal applications.

Miners are focused on finding new deposits, but other stakeholders want safe environments in and around mining areas. The same high-resolution SBG data sets used for exploration can enable whole new kinds of local monitoring of water, vegetation, and emissions to ensure safe and sustainable practices for industry and protections for society.

“There is a very strong, and established expert need for SBG, particularly if it can be free.”

## Commercial User

### Spectral geologists at mining companies

The exploration business is where it is at! The mining industry was an early adopter of remote sensing, which was oversold and underperformed. Now a new generation of spectral geologists not only wants to leverage new tools but make them easier to deploy and use with their exploration teams. Our teams want mineral maps not data.

This small spectral geology community sees the potential for SBG and is excited about the prospects.

“If there were finally an HIS up there, it would be huge!”

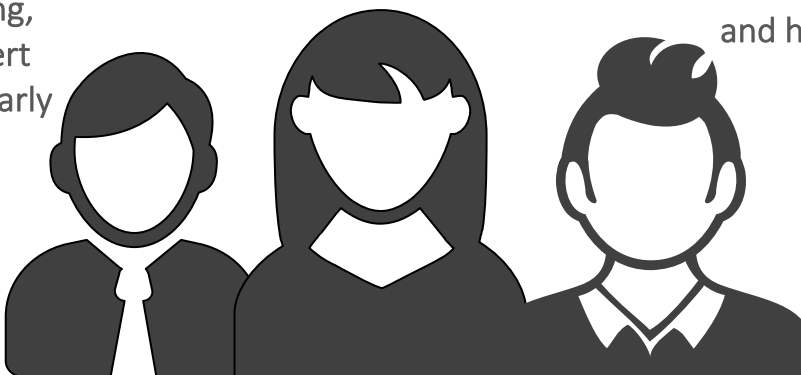
## Value-Added Service Provider

### Mineral mapping service providers

As developers of mineral mapping platforms, they have deep geology and remote sensing expertise. A convergence of digital tools and available data means the future of remote sensing is in data platforms.

They are more interested in high-resolution HIS and high-quality corrected data than formats and continuity. They will work out the details and build the tools; they just want NASA to bring operational, not just research, missions.

“ASTER already gives us most of what we need, for SBG to be a game changer <10 m and high SNR HIS should be the goal.”



# Mineral Resources—Valuation Context

## Observation Context and Challenges



Remote sensing has valuable applications across all stages of mining operations. Mining companies already have a good sense of the relative value that multispectral brings through use of ASTER and hyperspectral aerial flyovers for targeted applications. But most interviewees said the availability of global hyperspectral would be a game changer. The use of SBG for mapping and monitoring will reduce costs and increase effectiveness throughout exploration, opening and ongoing mining operations, and closing and remediation (see table on following page).

### How can satellite data help?

The largest benefit of SBG is likely to be in the exploration/discovery stage of mining operations. Greenfield and brownfield exploration/discovery would greatly benefit from SBG satellite capabilities. Exploration using remote sensing is evolving to be more than looking for “rocks” but finding more subtle, mineral, vegetation, and alteration signatures. Today most of the large global deposits of value have been “found.” So future greenfield reconnaissance work is about finding small-scale or difficult-to-image deposits.

### Challenges with current EO data products?

Current data and products do not support efficient and frequent large-area surveys. Vegetation mapping in association with soil/mineral deposits for exploration and environmental impact monitoring will be expanded if SBG capabilities are available. Exploration is typically regional (large scale 100s km<sup>2</sup>) or local-typical mine site (10–15 km<sup>2</sup>), and these scales and the kind of exploration and monitoring that occur dictate specific use cases and different desired spatial resolutions. SBG would afford more efficient larger area surveys compared with airborne fly-over surveys that are mostly one-off studies.

“Exploration costs for gold are currently ~\$0.55/oz, and HIS over larger areas could reduce this cost by reducing time, invested resources, and risk to field staff.”  
(Spectral Geologist, Leading Global Mining Company)



# Mineral Resources—Valuation

## Application Impacts

**SBG combined with in-field sensing would reduce the cost and investment risk of exploration efforts.** SBG-provided site and environmental monitoring would augment (not replace) in-field sensing, and these same capabilities and data sets could support brownfield exploration. This level of remote sensing would expedite and focus exploration efforts, reducing cost and investment risk.

**SBG could enable more affordable and comprehensive monitoring.**

Environmental/health monitoring for hazards, such as acid mine drainage, fugitive dust/particulates from operations, oil spills, and other natural mineral hazards, would be greatly enhanced by SBG. SBG would not only reduce the cost of this type of monitoring but make it much more comprehensive and effective.

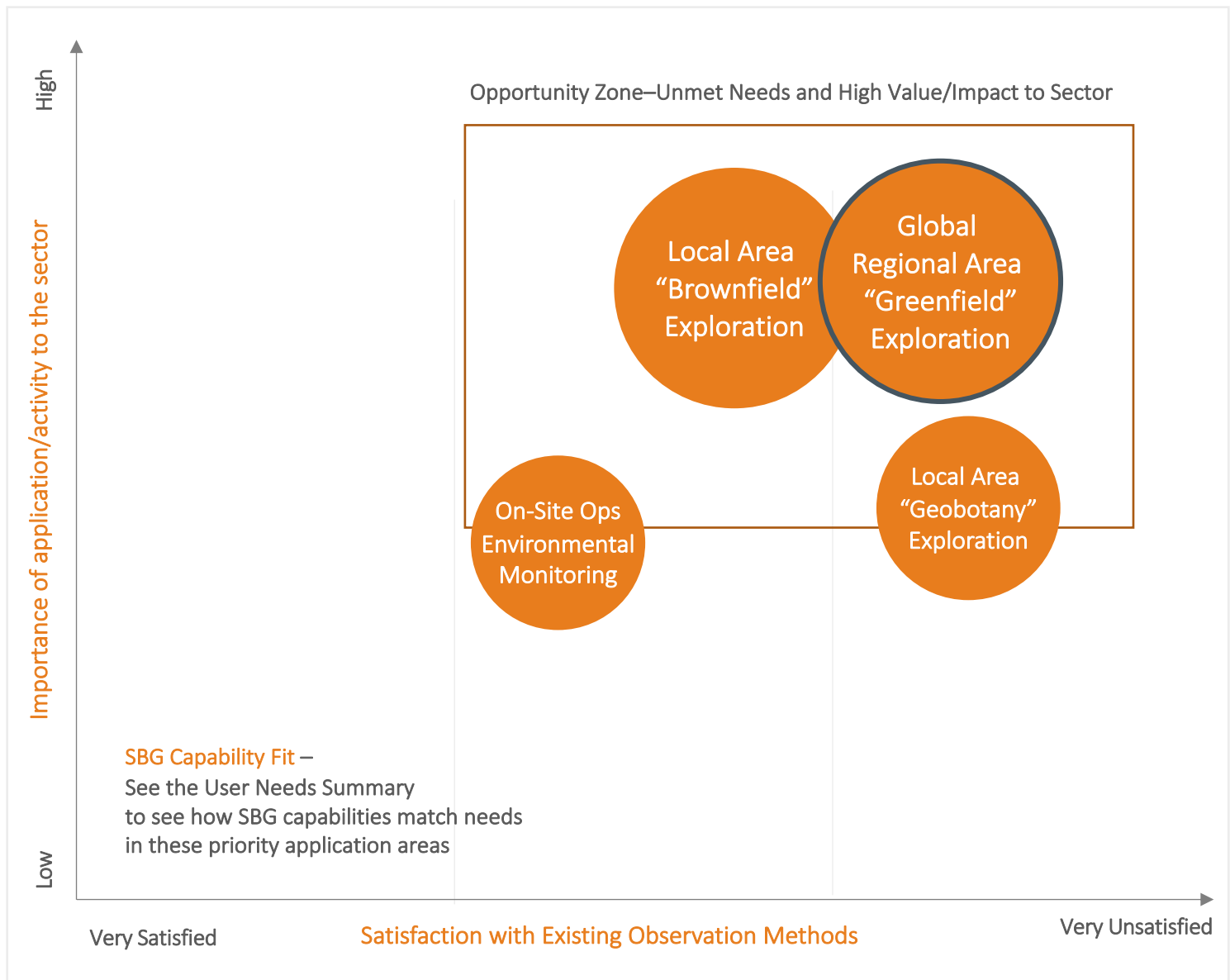
**SBG would provide better early warnings to avoid mining infrastructure safety hazards.** The physical/structural monitoring of mine dam and tailing piles could also help avoid catastrophic incidents. The temporal and spatial resolution of SBG would help baseline mapping/monitoring from which shifts or settling can be detected.

### Economic Value of SBG Related to Mineral Extraction

Use Cases	Application/Activity	Technical Impact with New Capabilities	Economic Value	Potential Magnitude of Impacts
Exploration and discovery	Regional surveys of greenfield areas and targeted local site brownfield exploration	Hyperspectral and TIR at scale – Large-area and local hyperspectral data on target mineral and alteration signatures	Reduced time and cost of large-area and target area exploration	High
	Combined mineral and vegetation exploration (geobotany) mapping			
Mine opening and operations	Vegetation monitoring for operational impacts	More comprehensive coverage and greater precision of monitoring activities	Lower operating costs and avoided environmental and health incidents	Modest
	Monitoring hazardous fugitive dust during operations			
Mine closing, reclamation, and monitoring	Monitoring acid water leachate from mines	More comprehensive coverage and greater precision of monitoring activities	Avoidance of environmental penalties and poor public relations  Reduced risk of catastrophic events	Modest
	Monitoring structural integrity of mining dams and tailing stacks			

# Mineral Resources—SBG Opportunity Zone

Areas with High Unmet Needs and Potential Value



Circle size indicates relative value of application.



Greenfield exploration and discovery is likely to have the greatest impact in terms of both importance and value for mining companies and SBG fit. This application was selected for the case study that follows.

# Mineral Resources—Valuation Case Study

Greenfield exploration and discovery alone represents >\$2.5B in potential value to the mining industry.



## Exploration/Discovery of Greenfield/Regional Areas

- Spectral geologists at mining companies said that SBG has the potential to provide the mineral extraction industry with global, large, regional, hyperspectral data at a spatial resolution of 30 m.
  - The data could be used as a screening tool over large areas to focus where ground-based sampling activities would be most likely to find productive deposits.
  - Screening could be conducted noninvasively without the need to send company individuals/representatives into remote or protected areas.
- Currently, exploration/discovery accounts for approximately 2% of total mining company costs, on average.
- The use of SBG hyperspectral could potentially reduce initial exploration time and expenses significantly, potentially reducing from 3 years to 3 months the time needed for large tracks of land. This use has the potential to reduce exploration costs by 60% to 70%.
- The use of SBG hyperspectral also has the potential to increase discovery from a given track of land, locating deposits that might otherwise have been missed. This use could potentially increase productivity of leases by at least 30%.

US Mineral Extraction (2018)	Value (Million)	Source
Industry size	\$50,000	US BEA
Exploration accounts for 2% of cost	\$1,000	PwC for World Bank Report
60% reduction in exploration costs	\$600	Interviews: Spectral Geologists
Leases account for 32% of cost	\$7,000	PwC for World Bank Report
30% increase in productivity of Lease	\$2,100	Interviews: Spectral Geologists
Total annual value	\$2,700	

# Mineral Resources—Valuation

## Additional Valuation Vignettes



### Monitoring During Opening and Mining Operations

Opening and ongoing operations account for the majority of expenses for mining companies. Thus, even small improvements in productivity or efficiency can represent sizable cost savings.

Although monitoring costs during mine operations are hard to quantify, cost savings from using SBG could be significant, particularly in the following areas:

- Streamlining of vegetation monitoring from surrounding areas, minimizing environmental impacts and potential resulting fines and local public relations issues
- Enhanced screening for hazardous fugitive dust associated with operations, reducing potential health impacts

Although it is hard to estimate prospectively, it is possible that SBG's hyperspectral capabilities and improved spatial resolution could reduce monitoring costs by 20%, while also making them more precise and effective.

### Monitoring During Closure and Post-mining Operation Monitoring

Again, it is difficult to quantify post-closure monitoring costs for a typical mine or company. However, SBG's capabilities will likely be beneficial for a range of monitoring activities:

- Screening for acid drainage from mines and development of baselines for naturally occurring acidity to better estimate the incremental impact/contribution from mines.
- Monitoring of vegetation and progress/productivity of remediation activities

Using hyperspectral imaging shortens the mapping time from 2 years to 2 months and saved ~\$2M in remediation costs. But exact calculations of the value/cost of environmental impacts are not widely reported or studied.



# Mineral Resources—Users Interviewed



## Key Informant

## Perspectives



Mark Landers, *SpectIR*



Cindy Ong, *CSIRO Energy*



Charlotte Bishop, *Geologic Remote Sensing Group*



Brian Cellura, *Newmont*



Adele Seymon, *AMIRA*



Brigette A. Martini, *Anglo American*



Pam Blake, *Boeing*



Lori Wickert, *Descartes Labs*

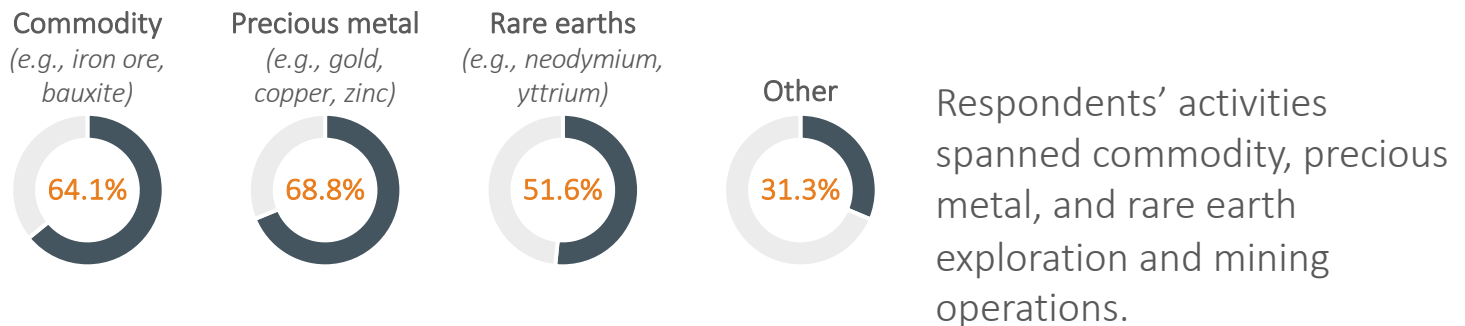


# Mineral Resources—Survey Results

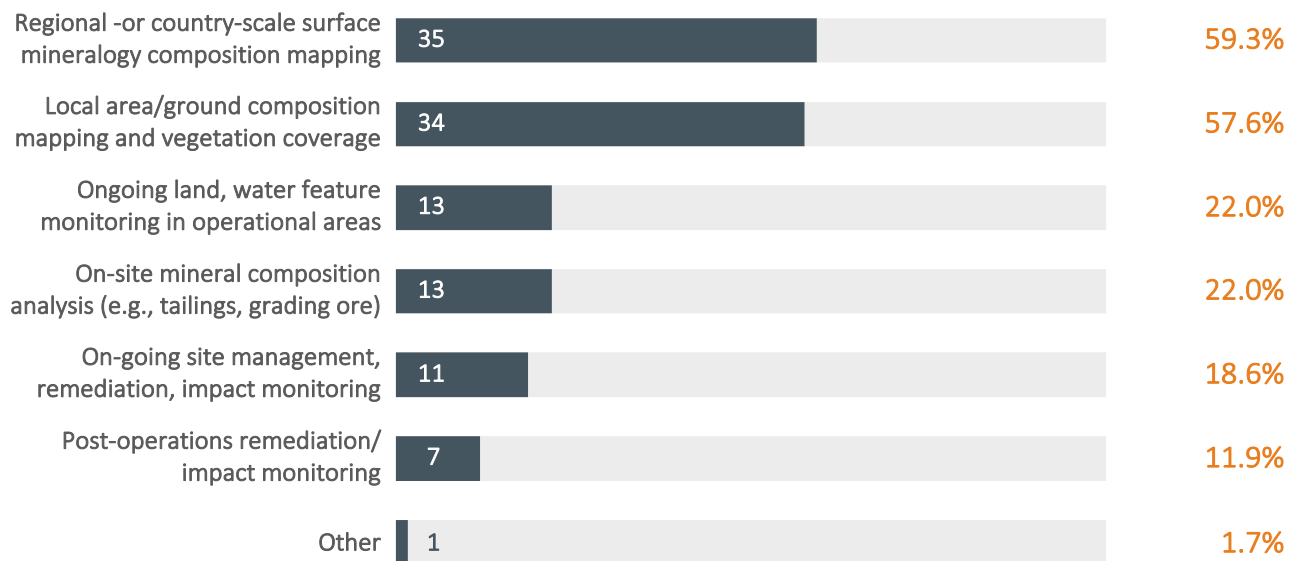
## Priority Applications



Survey respondents were asked about the kind of mineral exploration or mining their organization is involved in.



Respondents were asked to identify the top 2 most important “activities” that their organization is trying to accomplish.



Most respondents indicated that exploration activities—both regional and local scale—were the top 2 most important to their organization. This and other captured comments indicate the high priority and remote sensing needs expectations that the mining sector places on exploration activities.

# Mineral Resources—Survey Results

## Satisfaction with Current EO Data, SBG Improvement



*To what extent is the current remote sensing and Earth observation data you use adequate for the following mining phases?*

	Not at All Adequate		Slightly Adequate		Moderately Adequate		Very Adequate		Completely Adequate		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Exploration	2	3.4%	17	29.3%	26	44.8%	10	17.2%	3	5.2%	58
Opening	5	10.2%	15	30.6%	18	36.7%	9	18.4%	2	4.1%	49
Operations	5	9.4%	15	28.3%	16	30.2%	12	22.6%	5	9.4%	53
Closure/ reclamation/ restoration	4	7.1%	17	30.4%	17	30.4%	15	26.8%	3	5.4%	56

*For your organization's top two most important activities, to what extent could mining activities or processes be improved with the SBG platform capabilities?*

	No Improvement		Mild Improvement		Moderate Improvement		Significant Improvement		Re-sponses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Regional- or country-scale surface mineralogy composition mapping	0	%	0	%	4	13.3%	26	86.7%	30
Local area/ground composition mapping and vegetation coverage	0	%	0	%	5	17.2%	24	82.8%	29
Identification of key alteration minerals	0	%	0	%	0	%	0	%	0
Baseline mineral, water, vegetation mapping	0	%	0	%	0	%	0	%	0
Ongoing land, water feature monitoring in operational areas	0	%	0	%	4	40.0%	6	60.0%	10
On-site mineral composition analysis (e.g., tailings, grading ore)	0	%	1	9.1%	3	27.3%	7	63.6%	11
Ongoing site management, remediation, impact monitoring	0	%	0	%	2	20.0%	8	80.0%	10
Post-operations remediation/impact monitoring	0	%	0	%	1	16.7%	5	83.3%	6
Local land, water, and vegetation impact monitoring	0	%	0	%	0	%	0	%	0

# Mineral Resources—Survey Results

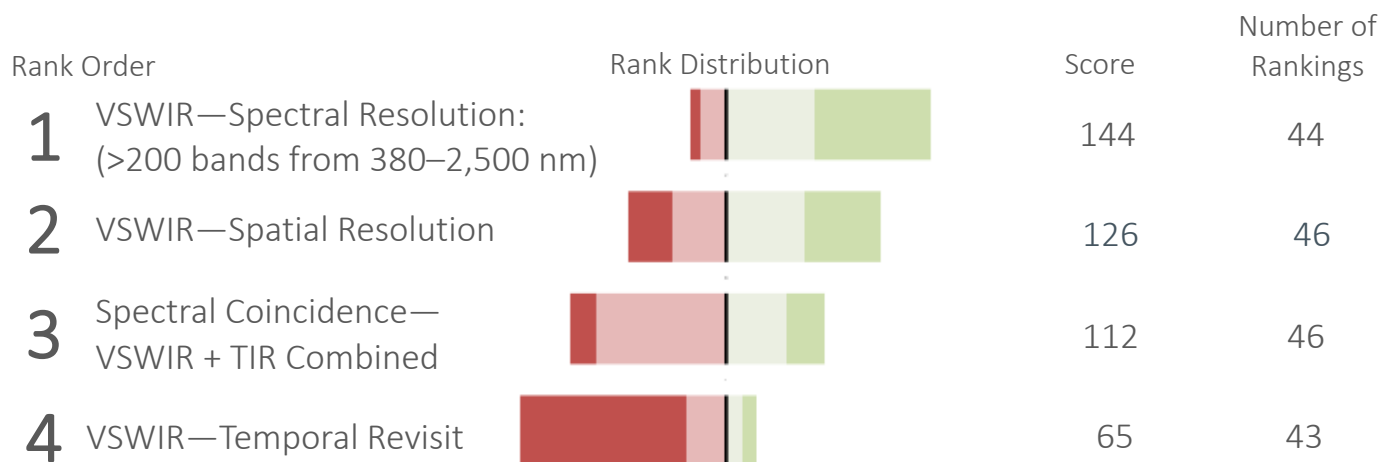
## Most Desired SBG Capabilities



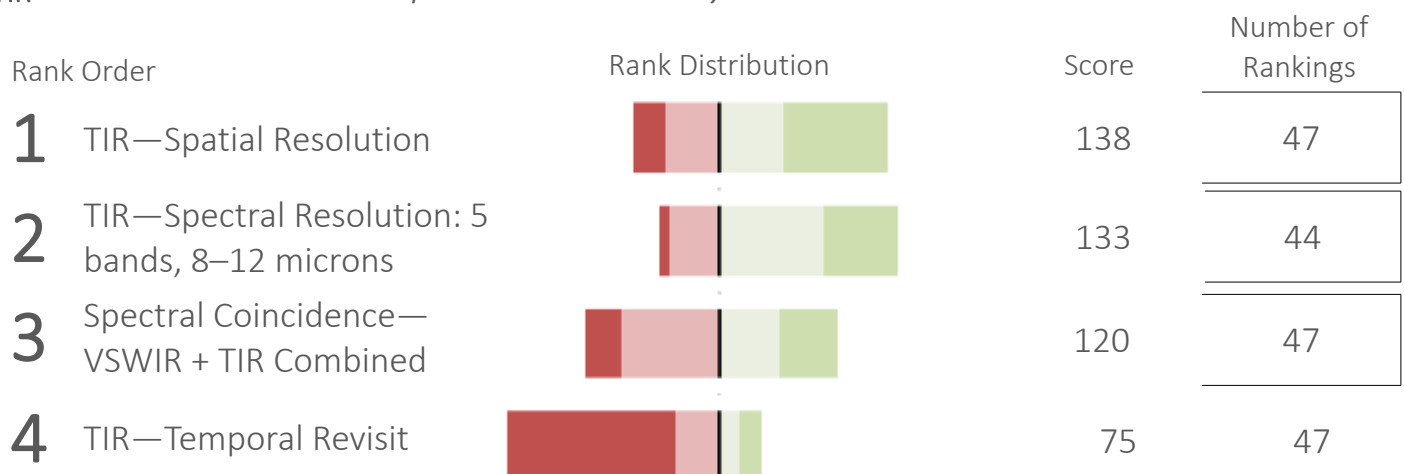
The size of the bar segments in the figures below indicate the number of respondents who ranked each capability #1 (area of right-most segment) to #4 (left-most segment). A weighted average was then used to generate the score and rank order.



Rank order—*Which capability would most improve your ability to do the two most important activities you selected earlier?*



Rank order—*Which capability would most improve your ability to do the two most important activities you selected earlier?*



The spectral and spatial resolutions of SBG are the critical capabilities for the mineral resource mapping user community. It is interesting to note how much less important temporal revisit is than any other criteria.

# Mineral Resources—Survey Results

## Latency and Information Quality Priorities



*For the most important mineral resource mapping activities, to what degree are the following levels of data latency adequate?*

	Greatly improves activities		Adds some additional improvement		Adequate to accomplish activities		Minimum necessary to accomplish activities		Inadequate - cannot accomplish activities at this level		N/A or Unsure		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
<24 hours	20	41.7%	7	14.6%	7	14.6%	2	4.2%	0	%	12	25.0%	48
<48 hours	7	14.9%	17	36.2%	10	21.3%	1	2.1%	1	2.1%	11	23.4%	47
<1 week	10	20.4%	10	20.4%	15	30.6%	5	10.2%	2	4.1%	7	14.3%	49
<1 month	6	12.5%	7	14.6%	9	18.8%	11	22.9%	9	18.8%	6	12.5%	48
More than 1 month	2	4.4%	2	4.4%	9	20.0%	10	22.2%	13	28.9%	9	20.0%	45

*For the use of Earth observation data in mining, how important are the following information quality and accessibility issues?*

	Not at All Important		Slightly Important		Moderately Important		Very Important		Extremely Important		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Cloud-free, usable imagery	0	%	1	2.0%	3	5.9%	18	35.3%	29	56.9%	51
Event driven	8	15.7%	7	13.7%	13	25.5%	16	31.4%	7	13.7%	51
Data continuity	0	%	4	8.0%	9	18.0%	22	44.0%	15	30.0%	50
Data and data product standardization	0	%	2	3.9%	6	11.8%	22	43.1%	21	41.2%	51
Information cost	2	3.9%	7	13.7%	11	21.6%	15	29.4%	16	31.4%	51

# Key Value Chain Players

Value-Added Service Providers



# Value-Added Service Providers—Community Overview\*

SBG could be a game changer, but service providers need NASA to develop the science and ensure data and data product quality.



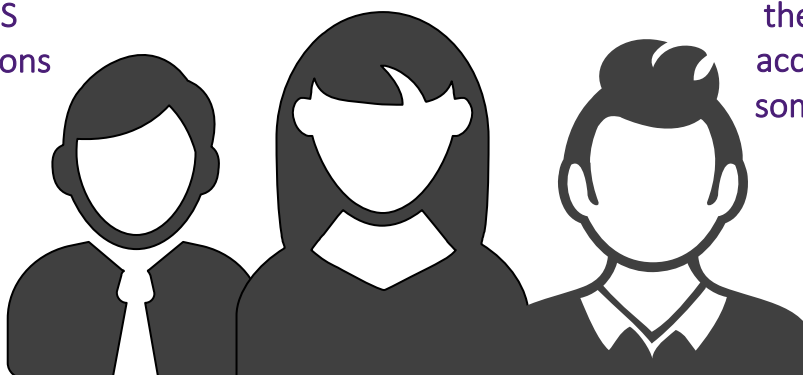
**This is the most willing and able community of practice.** Many VASPs are already actively working in the SBG primary application areas and are well known to NASA. These organizations sit at a critical part of the value chain for SBG because they are actively involved in, and motivated about, advancing the science and applied use of satellite spectral data, which aligns very well with NASA SBG's interests. Yet also, very importantly, they have their own commercial interests and those of their many customers at stake when using EO data and developing data products and services from those data sources. **VASPs expressed universal excitement about the potential of SBG, and they are a critical link to the kind of private- and public-sector end users that NASA would like to engage with and serve.** Expert practitioners within the VASPs are highly sophisticated users of the kind of observation data that SBG could produce, and they represent an important community of practice for SBG to engage, support, and nurture.

**These sophisticated users are looking to specific NASA leadership.** Many VASPs see the future of remote sensing as being driven by data science and modeling, which will require enhanced data sets, better analytical tools, and accessible cloud-computing platforms. The potential of SBG to provide complex hyperspectral data sets will only drive the need for better applied data science solutions. They also acknowledge that no major EO platform VASP companies (e.g., Esri, Descartes) or specialists (e.g., Technosylva) are using HIS, let alone coincident with TIR data sets. Although in theory they can handle complex data sets, as a practical matter such use has not been established. They cannot drive these data and application advances by themselves, so **VASPs will look to NASA to take a leadership role in developing these areas and are excited to partner with NASA to evolve the field.** Another key part of NASA SBG's value proposition is that VASPs trust NASA's credibility and capabilities compared with other satellite HIS developers to ensure high-fidelity data, transparent data processes, corrections, verification, and accessibility. These information quality factors are a huge priority to VASPs.

"I would love to be involved with developing HIS commercial applications with NASA SBG."

"SBG could be a game changer."

"I trust NASA to provide the data transparency, access, and quality that some others just can't."





# Value Added Service Providers—Community Overview\*

Skilled practitioners have learned to be cautiously optimistic but see lots of work to be done before SBG is commercially usable.



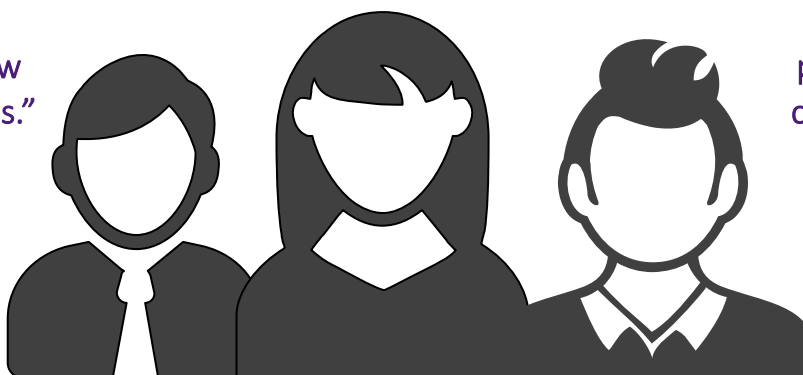
**Practitioners are hopeful but not convinced that SBG can meet operational needs.** Many VASPs are skilled spectral data imaging and analysis practitioners. Based on this experience, **they expressed concerns that the SBG hyperspectral capabilities exceed practical utility** and at the expense of more operationally useful capabilities like <10-m spatial resolution and <2-day revisits. In practice, they see diminishing returns with overly narrow, potentially redundant spectral bands that could lead to counterproductive spectral mixing. The use of HIS from airborne platforms has demonstrated the potential, but practitioners wondered if the global coverage advantages of a satellite platform might in practice be offset by poor spatial resolution and spectral mixing.

**Data product and model developers see the need for more applied science and operational viability.** Practitioners and VASPs also noted that there is still a lot of applied science work to do before their end-user clients have the commercially usable decision-making and modeling tools they desire. For example, VASPs working closely on imaging spectroscopy applications recognize that HIS compositional analysis of aquatic and terrestrial organisms still needs more hyperspectral ground-truthing and scientific validation. Developers of ET models and algorithms are uncertain how much SBG's capabilities will specifically improve ET, but they know a lot more work is needed before ET models can be integrated with many other data sources to affect agriculture applications. As noted before, because combined HIS and TIR imaging data are not widely used, the true value of these data sets is not well understood in these circles. However, they also are wary of “just another research mission,” and if they are to build services around NASA data, they want it to be “operationally viable.” Like NASA, VASPs see the opportunity for applied science and operational tools to mature significantly over the coming years as the SBG mission planning advances, so they see this as an opportunity for NASA to engage practitioners now to support this maturation in a commercial context, not just in a research context.

“I would gladly take 60 bands at 15-m resolution every few days, over 200 bands.”



















“SBG needs to think about commercial usability.”

“We need missions that will reliably provide operational commercial use, not just research.”



# Value-Added Service Providers—Users Interviewed



	Key Informant	Organization Type
	<u>Mark Landers</u> , <i>SpectIR</i>	
	<u>Lori Wickert</u> , <i>Descartes Labs</i>	
	<u>Molly Brown</u> , <i>6<sup>th</sup> Grain</i>	
	<u>Nate Torbick</u> , <i>Applied GeoSolutions</i>	
	<u>Mark Tracy et al.</u> , <i>Cloud Agronomics</i>	
	<u>Tom Mueller</u> , <i>Geospatial Technical Solutions</i>	
	<u>Joaquin Ramirez</u> , <i>Technosylva, Inc.</i>	
	<u>Curt Hammill et al.</u> , <i>Esri</i>	
	<u>Bill Salas</u> , <i>Applied GeoSolutions</i>	

# Appendices

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- I. Survey Results
- II. Project Approach and Methods

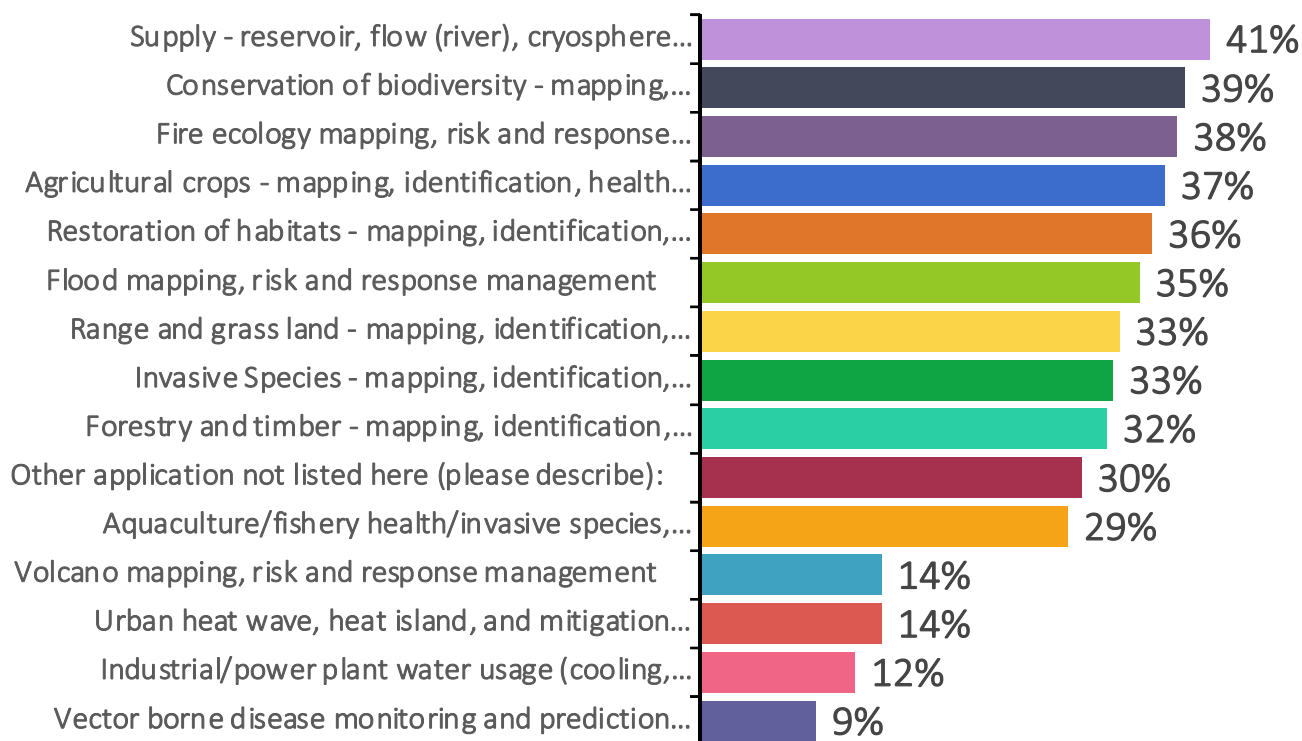
# APPENDIX I

## General Survey Results

# General Survey—Applications Data

The survey was designed to target primary application areas, but many other applications were also represented.

Which of the following application areas is your organization actively involved in?



Additional applications (e.g., vector-borne disease, urban heat wave, industrial power plant water, and volcano risk mapping) were reflected in the response rates.

It is worth noting the large percentage of “other applications.” A review of those other applications indicates that many of them are generally related to, but are a specific kind of activity or use case within one of, the primary applications areas.

However, a variety of unique applications (e.g., coal fire monitoring, “Call 811 before you dig,” and permafrost) and general categories (e.g., education, policy research, intelligence, and human activity) underscore the broad range of application activities of those that responded.

# General Survey—Modes of Observation

Users rely on a mix of direct and remote sensing observation methods.

For your primary application, which of the following methods does your organization use on an ongoing basis?

	Frequently		Occasionally		Never		Responses
	Count	Row %	Count	Row %	Count	Row %	Count
Human observation and instrument-based field studies	123	68.0%	46	25.4%	12	6.6%	181
Distributed or networked ground-based sensors deployed in the field	72	41.1%	59	33.7%	44	25.1%	175
Drones and UAVs*	34	19.2%	99	55.9%	44	24.9%	177
Airborne platforms*	57	32.4%	76	43.2%	43	24.4%	176
Satellite platforms*	129	69.7%	46	24.9%	10	5.4%	185

Analysis of responses by different user groups (e.g., direct users of EO data vs. research users of EO data; federal government vs. academic vs. commercial) showed that there was not much variation in the mix or frequency of observation methods employed and mirrored the total response set above.

As can be seen, a combination of field-based and satellite-based observations is most frequently used across a wide variety of applications.

The high percentage of frequent and occasional satellite observation users also suggests that the respondent set should be reasonably knowledgeable about the use of satellite data and data products for remote sensing observations in their application areas.

# General Survey—Direct vs. Research Users

Direct and research user respondents generally use the same mix of remote sensing and imaging platforms.

When you use remote sensing (RS) and imaging, which specific platforms do you typically use?

		Spectral Data Types Used								
		Low-resolution, multispectral satellite imagery, such as MODIS or VIIRS	Moderate-resolution multispectral satellite imagery, such as Landsat, Sentinel, ASTER	High-resolution multispectral satellite imagery, such as WorldView	Visible to Shortwave Infrared (VSWIR) Spectral Data	Thermal Infrared (TIR) Spectral Data	Airborne multispectral imagery	Airborne hyperspectral imagery	Moderate or high resolution LIDAR or Radar	Other
Direct User	Frequently	21	60	28	42	32	16	12	27	2
	Occasionally	39	21	39	22	36	43	41	44	0
	Never	18	2	16	16	14	23	29	11	0
Research User	Frequently	26	40	13	31	19	11	14	18	3
	Occasionally	22	22	29	20	34	28	29	32	2
	Never	15	4	21	11	9	22	18	12	0

The most frequently used platform of both—direct users and research users—are moderate resolution multispectral satellite imagery, such as Landsat, Sentinel, and ASTER.

VSWIR spectral data are more commonly used than TIR spectral data.

Satellite platforms are more routinely used than airborne multispectral, HIS platforms or LiDAR/radar. Most common reasons cited for not using these platforms are cost and complexity.



# General Survey—Direct vs. Research Users

Respondents are moderately satisfied with how most spectral imaging capabilities meet their needs.

Please rate your satisfaction with how well these current remote sensing and imaging platform capabilities meet your needs.

		Spatial: VSWIR 30-m capability	Spatial: TIR 100-m capability	Spectral: VSWIR—Five (5) discrete bands across 430–900 nm, and two (2) SWIR 1570– 1,650 nm and 2,110–2,290 nm	Spectral: TIR— Two (2) discrete bands in 10.6– 12.51 micron region	Temporal: VSWIR—16 days capability	Temporal: TIR— 16 days capability	Coincidence: VSWIR and TIR- simultaneous capability
Direct User	Completely satisfied	1	0	1	0	0	0	4
	Very satisfied	20	6	12	8	6	3	9
	Moderately satisfied	34	24	23	24	18	17	18
	Slightly satisfied	12	22	13	15	35	33	20
	Not at all satisfied	7	17	8	6	7	8	6
	Do not know	12	16	27	31	18	23	27
Research User	Completely satisfied	0	0	1	0	5	4	5
	Very satisfied	11	3	11	8	5	6	11
	Moderately satisfied	33	19	21	23	17	12	15
	Slightly satisfied	12	17	9	9	14	15	10
	Not at all satisfied	0	8	8	5	10	12	3
	Do not know	5	15	9	13	9	12	16

Direct users and research users generally share the same levels of satisfaction with current remote spectral imaging capabilities. The differences in satisfaction will also depend on primary application. Thus, little can be inferred about slight differences between groups.

It is interesting to note the high level of “do not know” responses across the board in both user groups. This suggests that a meaningful percentage of respondents may not be familiar with the specific and relevant capabilities of remote spectral imagers.

# General Survey—Direct vs. Research Users

Direct and research users state that SBG capabilities will be a substantial improvement for their primary application area.

Please indicate the extent to which each SBG capability listed could provide benefit in your primary application area.

		Spatial Resolution - VSWIR < 30 m	Spatial Resolution - Thermal Infrared (TIR) < 60 m	Hyperspectral Resolution - VSWIR (> 200 bands 380-2500 nm)	Hyperspectral Resolution - TIR > 5 bands 8-12 microns	Temporal Revisit - VSWIR	Temporal Revisit - TIR	Increased Sensitivity and Improved Accuracy
<b>Direct User</b>	Significant Improvement	28	26	32	23	31	38	45
	Noticeable Improvement	26	25	21	25	23	20	20
	Moderate Improvement	18	15	18	19	15	12	14
	Slight Improvement	7	7	7	6	7	5	0
	No Significant Improvement	2	7	2	5	3	4	0
<b>Research User</b>	Significant Improvement	20	19	24	15	14	20	28
	Noticeable Improvement	18	20	15	15	22	21	22
	Moderate Improvement	16	14	15	20	17	9	7
	Slight Improvement	4	5	4	6	3	5	2
	No Significant Improvement	3	3	1	4	5	5	2

Increased sensitivity and improved accuracy (of instrument and measurement data) was the most frequently selected capability providing a significant improvement, followed by TIR revisit and hyperspectral resolution—VSWIR.

Spatial resolution and temporal revisits were also rated as offering significant or noticeable improvement but by fewer respondents. Interestingly, these same capabilities were often the most cited as inadequate by interviewed experts in specific temporally dynamic application areas.

# General Survey—Information Quality

Cloud-free usable imagery, data quality, and cost are extremely important to all groups.

For your primary application area, how important are the following information quality and accessibility issues? (Definitions for each option were given.)

	Not at All Important		Slightly Important		Moderately Important		Very Important		Extremely Important		Do Not Know		Responses
	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count	Row %	Count
Cloud-free, usable imagery	0	%	2	1.5%	3	2.2%	37	27.0%	95	69.3%	0	%	137
Latency	2	1.4%	11	7.6%	40	27.8%	54	37.5%	37	25.7%	0	%	144
Data continuity	0	%	5	3.4%	14	9.5%	60	40.5%	69	46.6%	0	%	148
Data and data product	0	%	4	2.7%	25	16.9%	52	35.1%	66	44.6%	1	0.7%	148
Data Quality	0	%	0	%	6	4.1%	49	33.1%	93	62.8%	0	%	148
Information cost	3	2.0%	7	4.8%	21	14.3%	29	19.7%	84	57.1%	3	2.0%	147

Across different user groups, there was not much variation on the information quality and accessibility priorities.

Cloud-free usable imagery and data quality (accuracy, provenance, calibration/validation ensured by NASA) were both the most highly rated as extremely or very important to both direct and research users. Among all groups, data quality is also seen as being their second most important priority.

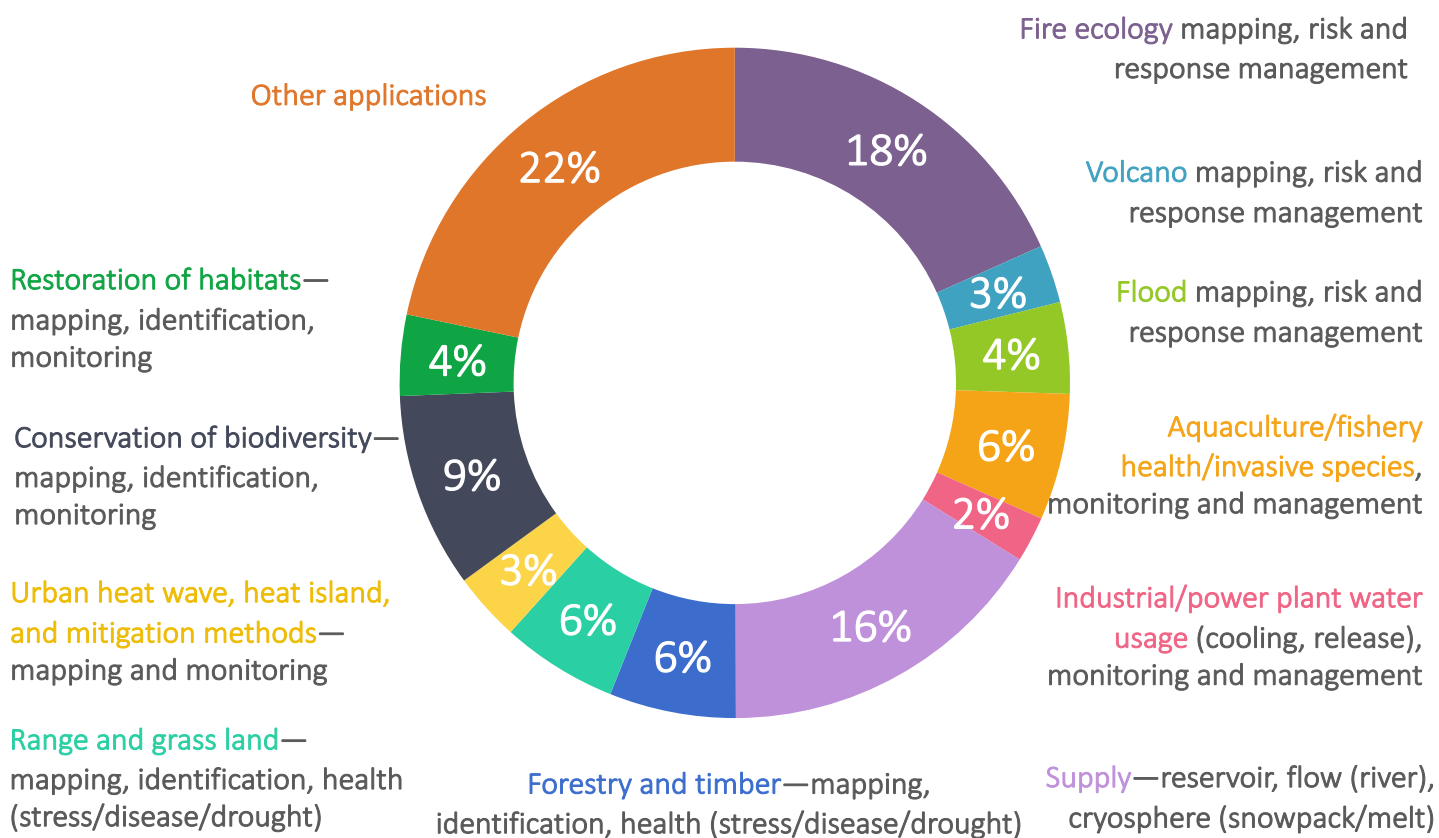
Information cost was of more importance to research users than to direct users, but both groups effectively ranked it their third highest priority.

# General Survey—Priority Applications Data

Respondents indicated their priority activities; the survey then asked about their needs and priorities specific to those activities.

Given the wide variety of application areas in which respondents are active, it was important to focus the detailed assessment only on respondents' most important activity. Subsequent questions focused only on the chosen activity.

Out of all the application areas your organization is involved in, which activity is most important?



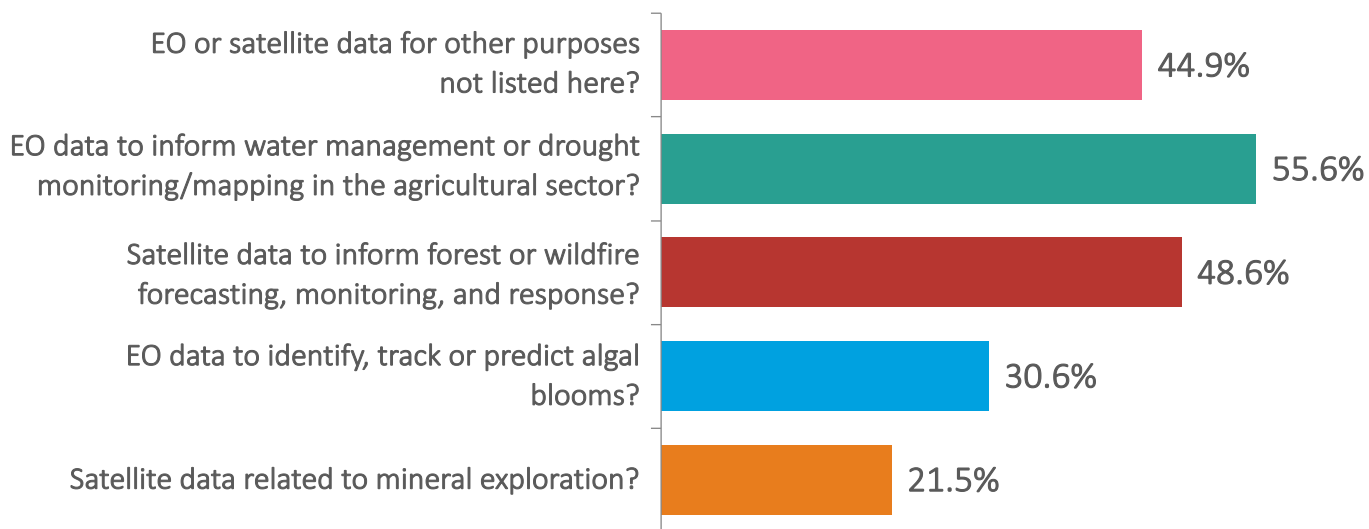
There was a strong representation across SBG-relevant application areas, beyond those that were prioritized for this survey.

# Primary Application Survey—Distribution

In addition to general questions, respondents chose a primary application area and survey section for a more detailed assessment.

As noted, the SBG User Needs survey was designed with two main sections—a general section and a primary application section. Respondents could choose to answer questions in one or more of the primary application areas (listed below), which were targeted by SBG for this focused user assessment effort. The primary application areas were selected to span the decadal survey science objectives; be relevant to private-sector, NGO, and local agency users; and leverage access to known user communities.

Has your organization ever used (or does it plan to use)?



The percentages are indicative of the distribution of respondents who then went on to answer a more detailed set of questions about their needs and priorities specific to their chosen application areas.

Respondents answering “other purposes not listed here” were directed to the general section, the results of which have been presented earlier in this report. Summary survey results by primary application area are provided in the [Findings](#) section of this report.

# Primary Application Survey—Latency

Users in each primary application area will accept and benefit from improved latency in different ways.

A specific set of general and application specific questions about latency were analyzed across all the four primary application areas and specific to each area.

For your most important activities, to what degree are the following levels of data latency adequate?

Table 1 - Sum of response across all application areas combined

Latency	Greatly improves	Adds some improvement	Adequate	Minimum	Inadequate	N/A or Unsure
< 24 hrs.	162	44	29	6	4	27
< 48 hrs.	72	101	47	12	11	27
< 1 week	34	49	96	50	30	14
< 1 month	19	18	41	67	105	24
> 1 month	9	7	24	48	142	38

Table 2 – Responses by application area

Latency	Application	Greatly improves	Adds some improvement	Adequate	Minimum	Inadequate	N/A or Unsure
< 24 hrs.	Algal	38	7	2	1	1	1
	Fire	51	14	7	3	3	8
	Mining	20	7	7	2	0	12
	Water	53	16	13	0	0	6
< 48 hrs.	Algal	14	20	9	4	1	1
	Fire	20	30	9	5	9	11
	Mining	7	17	10	1	1	11
	Water	31	34	19	2	0	4
< 1 week	Algal	2	12	12	17	6	1
	Fire	9	13	30	13	17	4
	Mining	10	10	15	5	2	7
	Water	13	14	39	15	5	2
< 1 month	Algal	2	1	2	13	30	2
	Fire	3	5	10	19	39	9
	Mining	6	7	9	11	9	6
	Water	8	5	20	24	27	7
> 1 month	Algal	2	0	0	7	34	6
	Fire	2	1	8	10	53	10
	Mining	2	2	9	10	13	9
	Water	3	4	7	21	42	13

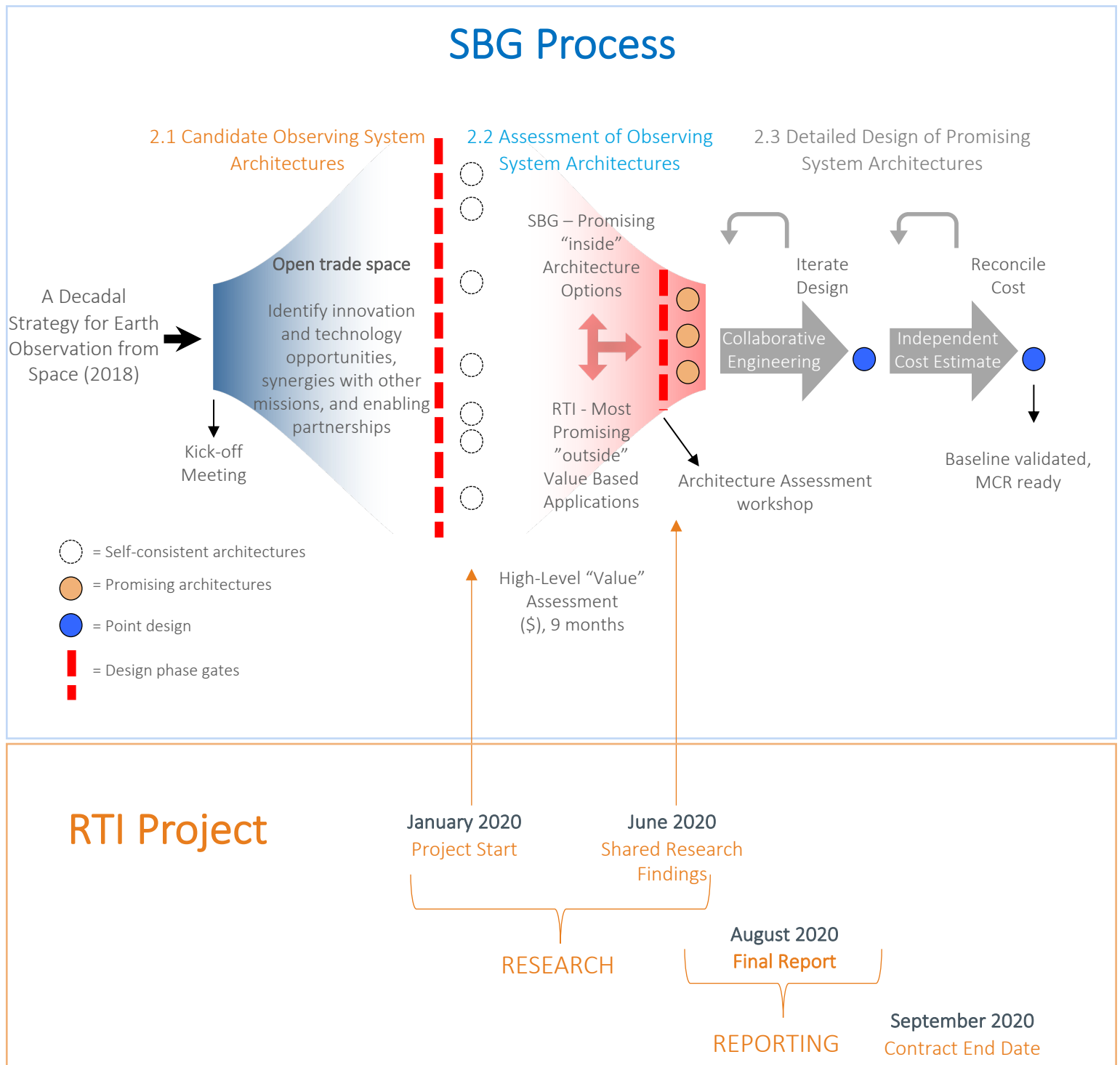
Fire and HAB applications, those that are observing more dynamic environments and trying to manage risk, want the best latency (<24 hrs); this mirrors responses about temporal revisits. Other areas still see improvement with longer latency, but all indicate latencies over a month are inadequate.

# APPENDIX II

## Project Approach and Methods

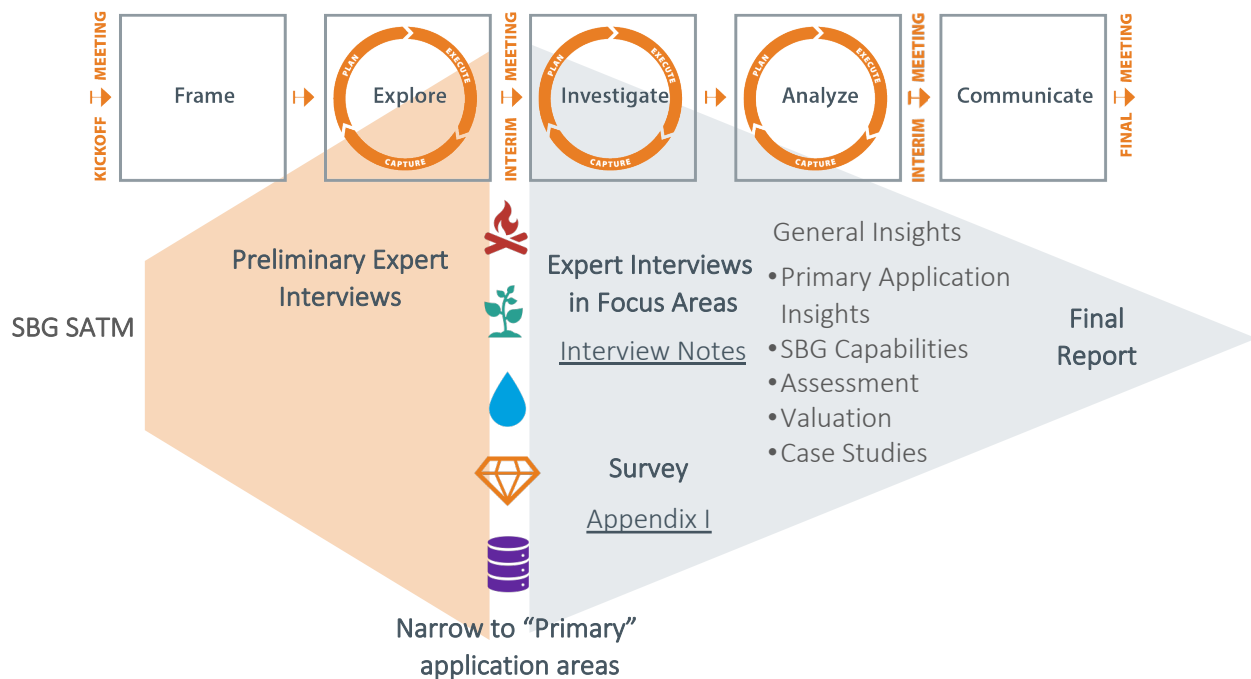


The RTI project brought comprehensive insight from new groups of end users to inform SBG’s architecture down-selection process.



RTI used a structured research process to divergently explore user applications and a detailed investigation of user needs and value.

## RTI INNOVATION ADVISORS' RESEARCH PROCESS



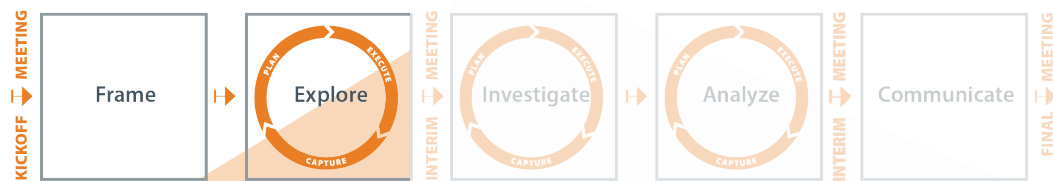
RTI's approach used principles of design-driven development and considered users' **desirability** (needs) and **viability** (valuation) to inform SBG's consideration of technical **feasibility** (capabilities and architectures) and users' "jobs to be done."

## DESIGN-DRIVEN USER NEEDS AND DESIRED SBG CAPABILITIES ASSESSMENT

OPPORTUNITIES Users desired application or "job to be done"	CAPABILITIES Required characteristics to deliver desired application or complete the job to be done?	CONCEPTS Technology/design options to realize desired characteristics
What is the desired user application or job to be done? What are the user criteria for this application or job?	What does the platform need to do? To deliver the user criteria the platform should ...	How will the platform do this? How can it be done?

The Frame and Explore stages set “current use” and prospective SBG capability sets and chose “primary” applications to focus the research.

## OBJECTIVES OF THE FRAME & EXPLORE STAGES



1

Define a  
“current use”  
capability set

Determine the current capabilities of relevant Earth observation programs of record. This currently used capability set will serve as a baseline “counterfactual” for the valuation assessment.

2

Define a  
prospective  
SBG capability  
set

Determine the prospective SBG DO capabilities that will be used to assess the potential benefits and value to users. This approach ties user valuations to SBG capabilities to inform architecture decisions.

3

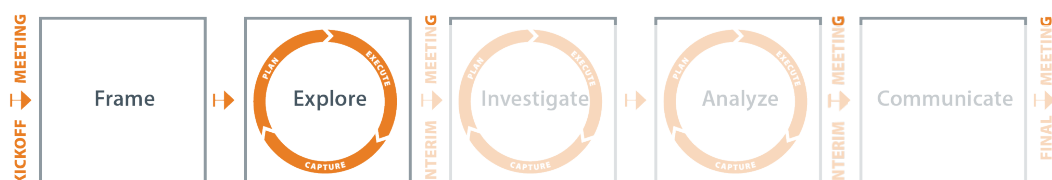
Explore and  
select  
“primary”  
applications

Choose an initial set of application areas to consider from among many possible SBG applications. Then down-select a four “primary” applications which span SBG science objectives and are also relevant to nontraditional , nonresearch end users.

Iterations with the SBG Application team confirmed platform capability sets that included both “counterfactual” and prospective.

## FRAME & EXPLORE OBJECTIVE 1 & 2:

### DEFINE A ‘CURRENT USE’ AND PROSPECTIVE SBG CAPABILITY SET



RTI worked with the SBG Applications team to determine appropriate relevant programs of records and settled on Landsat 8 and Sentinel 2 as valid satellite spectral imaging capabilities to use as existing and “currently used” capability sets. Using the SATM and SBG capability codes we determined the prospective SBG platform capability sets. The capability sets were critical to subsequent interview and survey methods and allowed us to connect user needs and valuation research insights back to specific SBG capabilities.

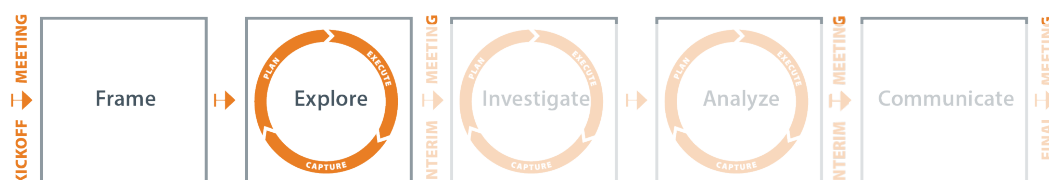
### “Baseline” and Prospective SBG Capability Set

Capability Set	VSWIR Spatial	VSWIR Temporal	VSWIR Range	VSWIR Sensitivity	TIR Spatial	TIR Temporal	TIR Range	TIR Sensitivity	VSWIR/TIR Coincidence
Prospective NASA SBG Platform	≤30 m	≤16 days for global coverage *	≤380– ≥2500 nm @ ≤10 nm	SNR ≥ 400 VNIR, SNR ≥250 SWIR, accuracy ≤10%	<60 m	≤3 days for global coverage*	≥5 bands in 8-12 um	≤1K absolute, ≤0.2K NeDT/ band	Simultaneous within 30 seconds
Existing Observing System Platforms*	30 m	16 days	430–90 nm 1,377 nm over 8 bands	SNR ~200	100 m	16 days	2 bands in 10.6–12.51 um		Simultaneous

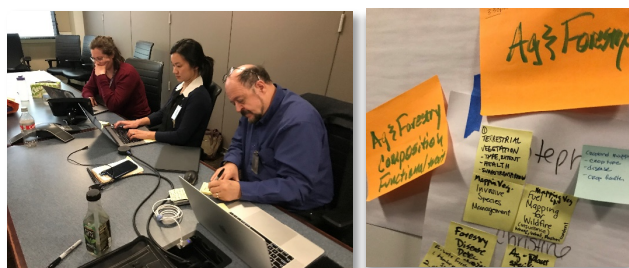
\*Based on Landsat 8 and Sentinel 2 capabilities

RTI facilitated an in-person working session to generate a preliminary list of promising applications for further exploration.

### FRAME AND EXPLORE OBJECTIVE 3: IDENTIFY PROMISING APPLICATION AREAS



#### Session with SBG Applications Team



#### Criteria for Application Areas

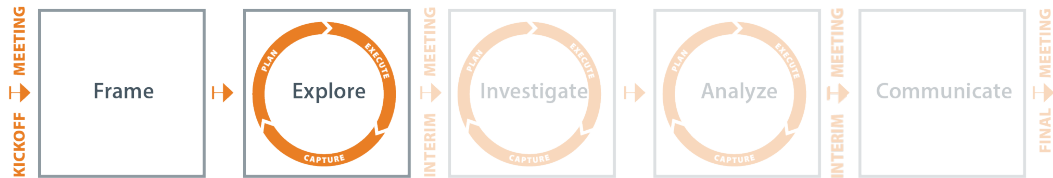
- Clear SBG differentiator (unique value proposition)
- New applications align across full SATM capability sets
- Good “examples” of SBG capabilities and case studies exist and can be used as reference
- Perceived/known interest of private and public users

#### Promising Application Areas Identified

<b>Public Health</b> <ul style="list-style-type: none"> <li>• Pollen monitoring</li> <li>• Algal bloom</li> <li>• Pollution/plastics</li> <li>• Water quality</li> </ul>	<b>Food &amp; Agriculture</b> <ul style="list-style-type: none"> <li>• Ag crop health/stress/damage</li> <li>• Ag crop type/genotype mapping</li> <li>• Irrigation/water use efficiency</li> </ul>
<b>Water &amp; Natural Resource Management</b> <ul style="list-style-type: none"> <li>• Aquatic plants</li> <li>• Phytoplankton</li> <li>• Water use management</li> <li>• Mineral mapping</li> </ul>	<b>Urban/Infrastructure Planning</b> <ul style="list-style-type: none"> <li>• Heat islands/mitigation</li> <li>• Cool-building mapping/monitoring</li> </ul>
<b>Forestry and Rangeland</b> <ul style="list-style-type: none"> <li>• Forestry/timber mapping</li> <li>• Forest disease/infestation</li> </ul>	<b>Conservation &amp; Restoration</b> <ul style="list-style-type: none"> <li>• Invasive species</li> <li>• Strip mining reclamation</li> </ul>

SBG expert interviews and secondary research informed an evaluation matrix for use in down-selecting to four primary applications.

### FRAME & EXPLORE OBJECTIVE 3: SELECT “PRIMARY” APPLICATIONS



Extensive interviews in conjunction with the SBG Application Team leads, enabled key applications to be assessed and down-selected. All promising application areas were scored using an evaluation matrix. Numerical scoring criteria were constructed to enable a semi-quantitative analysis of the application areas. Highest scoring application areas were chosen as “primary” areas for detailed investigation in the next phase of the RTI process. The scoring criteria considered the value SBG might uniquely provide to an application area, the feasibility of RTI’s assessment of that value, and the level of effort necessary to reach private- and public-sector users and user communities “not traditionally engaged” by NASA for a given application area.

### “Primary” Application Evaluation Matrix

	Value Proposition	Y or N?	Feasibility of Communicating Value	Y or N?	Known Experts	Y or N?	Known User Community	Y or N?	Research Level of Effort	Y or N?	Feasibility of Assessing Value	Y or N?
Evaluation Criteria	Assumed SBG differentiator		Case studies mentioned		Additional known experts posited		No specific user communities identified but contacts provided		Lots of research required for baseline understanding		Unclear approach to valuation	
	Multiple specific points of differentiation		Known literature with artifacts to demonstrate SBG differentiator		Reference to leads for experts for valuation or use cases		1-2 User communities identified		Specific leads provided but additional lead finding required		Possible approach but will require multiple points of validation	
	Solidly confirmed value proposition by expert		Easily gather from first round experts		Direct contact with experts for valuation and use cases		User communities with established lists or databases		Direct point of contact in user community and to relevant experts		Body of literature/data on existing valuation approach	
Score	One point per checked box (up to 3)		One point per checked box (up to 3)		One point per checked box (up to 3)		One point per checked box (up to 3)		One point per checked box (up to 3)		One point per checked box (up to 3)	

The primary application areas align with SBG SATM and accessible user communities and provided the necessary focus for user research.

### FRAME AND EXPLORE OBJECTIVE 3: SELECT “PRIMARY” APPLICATIONS

#### Application Evaluation Matrix Results



	Conservation of biodiversity	Fire risk mapping, response	Ag/crops/drought	Algal bloom monitoring and response	Heat wave/mitigation Vector-borne diseases	Mineral/energy resource composition and mapping
Value Proposition	1	3	2	1	1	3
Feasibility of Communicating Value	0	2	1	3	1	3
Known Experts	2	3	2	2	1	3
Known User Community	1	1	3	2	0	1
Research Level of Effort	1	3	2	2	1	2
Feasibility of Assessing Value	1	2	3	3	1	2
Score	6	14	13	13	5	14

Highest ranking application areas were selected for investigation after confirmation with the SBG applications team.

#### Primary Application Areas



Fire Ecology and Risk applications



Agriculture/ Water Applications



Algal Bloom/ Water Quality applications



Mineral Resource applications



General – Data Product Providers  
(added post evaluation)



The Investigate and Analyze steps included extensive user interviews and an online survey.

## OBJECTIVES OF THE INVESTIGATE STAGE



1

### Interview “key informants”

- Identify and engage key user communities and users
- Determine specific applications and outcomes of EO data and current limitations.
- Discover priority capabilities and ideal capabilities
- Probe for socioeconomic value of priority applications and capabilities

2

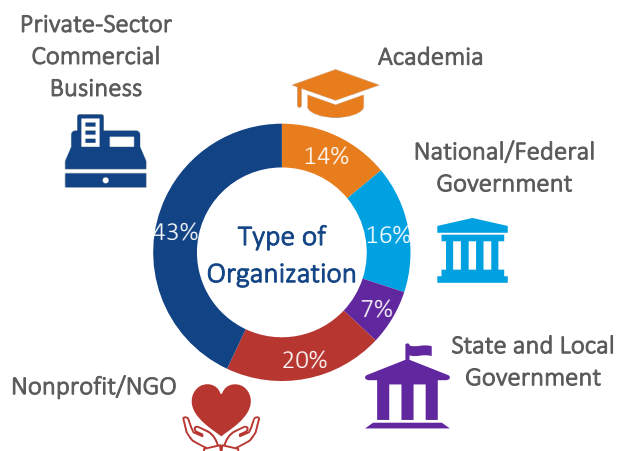
### Survey user needs and priorities

- Broadly probe current observation methods satisfaction and needs across a wide range of applications.
- Focus in on the four application areas targeted by this study to determine key needs, most desired SBG capabilities, and SBG value impacts.

# RTI conducted more than 40 key informant interviews, mostly with potential SBG nonresearch users who are not traditionally engaged by NASA for mission design.

## INVESTIGATE OBJECTIVE 1: INTERVIEW KEY INFORMANTS

### Interviews by Perspective

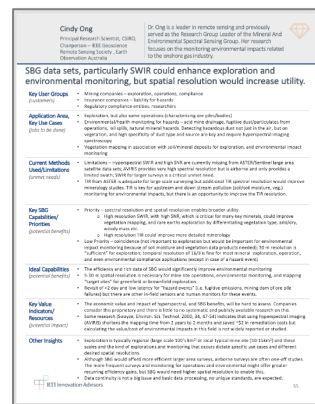
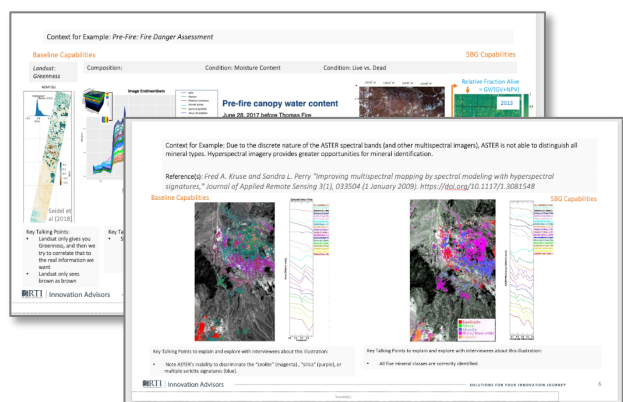


### Interviews per Primary Application Area



“Demonstration” slide decks for the four primary applications were compiled with extensive help from SBG experts. These included key talking points and visuals to help illustrate the value of SBG to users who may not have deep EO knowledge. The decks were provided before the interviews.

Key informant interviews were transcribed and summarized to capture key user and expert insights (See [Interview Notes](#), separate file.). Interview notes are organized according to design-driven elements, including customer insight, use cases, unmet needs, desired capabilities, and potential SBG impact.



### SBG Capability Demonstration Decks

### Key Informant Interview Notes

A custom online survey engaged over 20 user communities in the primary application areas and resulted in >500 unique responses.

## INVESTIGATE OBJECTIVE 2: SURVEY USERS NEEDS AND PRIORITIES

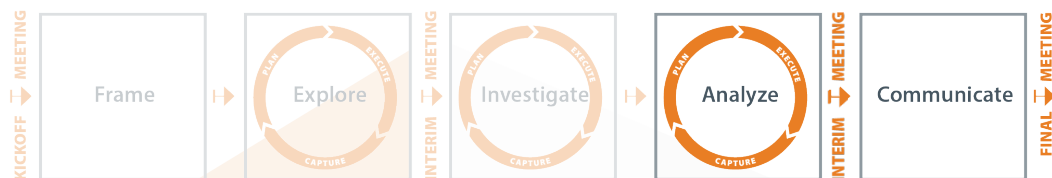
A custom and comprehensive online user survey was built with two sections: (1) general section that gathered insights on preferred modes of Earth observation, satisfaction with current remote sensing modes, and preferred SBG capabilities and (2) optional application-specific questions on the benefit and desirability of SBG in each of the four primary application areas. The survey also gathered respondent demographic data.



Survey Elements and Lines of Questioning	
General – Section	Introduction
	Query across expanded SBG applications list
	Establish (one or more) primary application(s) of importance
	Preferred modes of observation
	For primary application and current remote sensing (RS) modes – satisfaction
	For primary application – Assess most preferred SBG capabilities
	For primary application – Assess improvement and get value indicator
	Other open-ended questions
Sections for Fire, Ag/Water, Algal/Water Quality, Mining	
Application Specific – Sections	Confirm work focus in “primary” application area chosen (Provide detailed examples)
	Current ability to do observation work at high level
	SBG improvement in ability to do work at high level
	SBG Improvement in ability to do work in more specific sub-jobs specific to “primary” application area (Provide detailed examples)
	Determine priority of “sub-jobs” in archetype application areas
	Assess which SBG capabilities are most important in doing specific jobs in “primary” application of choice
	Assess importance of other SBG features
	Assess key features and factors for using SBG
	Describe value of SBG
	Organization type, industry, user type, EO data usage
Demographics	

The Analyze and Communicate steps distilled the research insights into key findings, summary overviews, and observations.

## OBJECTIVES OF ANALYZE AND COMMUNICATE STAGES



1

### Synthesize and analyze research findings

- Compile and summarize key informant interviews
- Compile, segment findings by application area and user types, and chart survey results
- Synthesize and analyze key themes, user needs and insights, capabilities, priorities, and value assessments
- Gather additional valuation estimate data

2

### Summarize general and application insights and valuations

- Build Findings sections for each “primary” application area
- Document interviews, survey results, and project approach and methods in appendices
- Develop executive summary and project overview with observations and recommendations

The final report reflects the breadth of analysis and frameworks used to synthesize findings and communicate key themes and insights.



Research findings for each primary application area were synthesized, and insights from the interviews and survey results were analyzed to distill key themes across several design-centered elements: user applications and user community profiles, user needs, and SBG capability priorities. SBG opportunity areas and valuations case studies and vignettes were compiled.

## Key Findings Focus on Primary Application Areas

### Application Overview

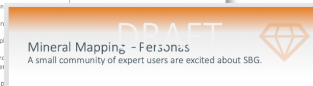


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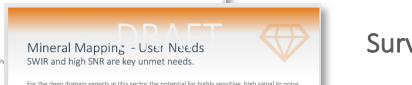
- 1 EXECUTIVE SUMMARY
- 2 PROJECT OVERVIEW
- 3 FINDINGS
- 4 APPENDICES
  - I. Interview Summaries
  - II. Survey Results
  - III. Project Approach and Methods



### Personas



### User Needs



### Survey Results



### Valuation Case Studies



### SBG Opportunities

