EVALUATION OF A RANGE OF LANDSAT DATA COST SHARING MODELS

A Report of the National Geospatial Advisory Committee
Landsat Advisory Group
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EVALUATION OF A RANGE OF LANDSAT DATA COST SHARING MODELS
Executive Summary

In early 2017, Department of the Interior (DOI) leadership requested that U.S. Geological Survey (USGS) consider possibilities for fee recovery for Landsat data. Accordingly, USGS asked the Landsat Advisory Group (LAG), subcommittee of the National Geospatial Advisory Committee (NGAC), to review the results from recent publications[1] in consideration of the plausibility of fee recovery for Landsat data. Subsequently, in August of 2018, the USGS modified the request to invite the LAG "to consider a range of possible Landsat data cost sharing models that may include, but are not limited to: resource leveraging for data processing, management, and distribution; resource leveraging for satellite ground mission development and operations; and various forms of fee recovery models for different market sectors." This report presents the findings of the LAG regarding the viability of several different Landsat cost sharing alternatives, as well as identifying a potentially more fruitful approach to reducing the overall cost of Landsat missions through the use of emerging and increasingly proven technologies.

The paper considers two types of fee recovery alternatives:

1. Charging fees for Landsat data with the characteristics of Landsat 8 and 9, and
2. Charging fees for "enhanced" Landsat data such as improved spatial or spectral resolution over Landsat 8 and 9, or tailored image-collection requests.

The LAG's findings and recommendation regarding charging fees for Landsat data with the characteristics of Landsat 8 and 9 are:

> ***Finding: The LAG believes that charging a fee for Landsat data will generate little net revenue. The net revenue would potentially be less than the government costs incurred to implement the fee.***
>
> ***Finding: The LAG believes that charging a fee for Landsat data will result in negative economic impacts to the U.S. commercial remote sensing satellite and value-added industries.***
>
> ***Finding: The LAG believes that given existing statutory and regulatory constraints, the Federal Government could not readily charge for Landsat data without substantive changes in both law and regulations.***
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> ***Finding: The LAG believes that the revenue obtained for charging a fee for Landsat data would not be worth the economic, legal, societal or political costs that would be incurred, particularly given the measures that would need to be required to change applicable law and regulation or to revoke internationally lauded and followed data policy.***
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> ***Recommendation: The LAG recommends that the Department of the Interior not implement any fees for Landsat data with the characteristics of Landsat 8 and 9.***

[1] Valuing Geospatial Information: Using the Contingent Valuation Method to Estimate the Economic Benefits of Landsat Satellite Imagery (Loomis et al, 2015), the 2012 NGAC Landsat Advisory Group Statement on Landsat Data Use and Charges, fgdc.gov/ngac/meetings/september-2012/ngac-landsat-cost-recovery-paper-FINAL.pdf, and other relevant studies.

The LAG's finding and recommendation regarding charging for "enhanced" Landsat data is:

> ***Finding: The LAG believes that there may be an opportunity to generate revenue by selling "enhanced" imagery products and tailored tasking options from sensors onboard Landsat satellites while still making standard Landsat 8 and 9 imagery data free and openly available. However, there are apparent and significant concerns or risks that could make such an option difficult to implement.***
>
> ***Recommendation: The LAG recommends further review of these concerns if this approach is considered.***

The paper also examined other approaches to cost-recovery or cost-avoidance for the Landsat program.

The LAG's findings and recommendation on such approaches are:

> **Finding: The LAG believes that moving from the current Government-owned, Contractor-operated (GOCO) business model, to a Contractor-owned, Contractor-operated (COCO) business model could provide for more efficient delivery of Landsat data and provision of data management services at lower costs.**
>
> ***Recommendation: The LAG recommends that further research is needed to examine the benefits and costs of transitioning from GOCO to COCO at the USGS Earth Resources Observation and Science (EROS) Center.***
>
> **Finding: The LAG believes a Public Private Partnership could allow the U.S. Government to benefit from some of the efficiencies of the private sector industry, while maintaining Landsat continuity. It could also preserve public/open availability of Landsat-quality data. However, this approach depends upon the ability of private industry to develop and implement a successful business model and upon any legal changes required including amending the Land Remote Sensing Policy Act.**
>
> ***Recommendation: The LAG recommends that further research is needed to determine if a sufficient business case exists and what legal changes are required to support exploration of the creation of public-private partnership(s).***

In conclusion, ***as the overall motivation for examining cost sharing alternatives is to reduce the public expenditures required to sustain Landsat data collections and continuity, the LAG believes that considering the findings of this report, a more significant study would be to analyze how the costs of building and launching Landsat sensors could be reduced, rather than focusing on cost sharing of operations.*** This is consistent with the LAG recommendation made in April of 2018, *"The U.S. Government should aggressively investigate rapidly emerging and increasingly proven technologies which could greatly reduce the cost of Landsat missions."*[2]

[2] "Recommendations for Possible Future U.S. Global Landsat Data Collections Beyond Landsat 9". A Report of the National Geospatial Advisory Committee Landsat Advisory Group. April 2018, fgdc.gov/ngac/meetings/april-2018/ngac-landsat-future-missions-recommendations-paper.pdf

Introduction

In early 2017, Department of the Interior (DOI) leadership requested that U.S. Geological Survey (USGS) consider possibilities for fee recovery for Landsat data. Accordingly, USGS asked the Landsat Advisory Group (LAG), subcommittee of the National Geospatial Advisory Committee (NGAC), to review the results from recent publications[3] in consideration of the plausibility of fee recovery for Landsat data. Subsequently, in August of 2018, the USGS modified the request to invite the LAG "to consider a range of possible Landsat data cost sharing models that may include, but are not limited to: resource leveraging for data processing, management, and distribution; resource leveraging for satellite ground mission development and operations; and various forms of fee recovery models for different market sectors."

This report presents the findings of the LAG regarding the viability of several different Landsat cost sharing alternatives, as well as identifying a potentially more fruitful approach to reducing the overall cost of Landsat missions through the use of emerging and increasingly proven technologies. Section 1 addresses the economic, legal, and political challenges of fee recovery alternatives. Section 2 discusses resource leveraging possible through public-private partnerships. The report is followed by Appendix 1 that provides the historical context for current Landsat pricing and licensing policies. Appendix 2 summarizes feedback from users, who submitted comments to the LAG from a variety of sources.

1. Fee Recovery Alternatives

This section of the paper considers two different types of fee recovery alternatives.

- Charging fees for Landsat data with the characteristics of Landsat 8 and 9
- Charging fees for "enhanced" Landsat data such as improved spatial or spectral resolution over Landsat 8 and 9, or tailored image-collection requests.

1.1. Charging Fees for Landsat Data with the Characteristics of Landsat 8 and 9

One cost sharing option would be for USGS to charge for data with the current characteristics of Landsat 8 and 9. The LAG has identified several alternatives under this option. These include:

- No change in current policy.
- Immediately instituting a fee for all archived and future Landsat data.
- Continuing "free and open" distribution of Landsat 8 and all previously collected and archived Landsat data, but begin charging for data collected by Landsat 9 and future Landsat missions.
- Continuing "free and open" distribution of previously collected and archived Landsat data, but charging users for immediate access to future collections, allowing free and open distribution only after the delay of a specified time period.
- Continuing "free and open" distribution of Landsat 8 and 9 for governmental and academic users, but charging commercial users.
- Continuing "free and open" distribution of all previously collected and archived Landsat data, as well as the non-thermal bands of future Landsats, but charging for access to newly collected thermal bands.

[3] See footnote 1

There are a number of economic, legal, societal, and political obstacles associated with any model of charging a fee for current and future Landsat data with characteristics comparable to Landsat 8 and 9.

Economic Obstacles

The purpose of charging a fee for Landsat data would be to generate revenue which could offset a portion of USGS's Sustainable Land Imaging Program costs. Successfully charging a fee requires that users actually purchase the data once a fee is charged. There are several reasons why the U.S. Government would likely receive minimal new net revenue from charging for Landsat data.

1. Under the current free and open data policies, the vast archive of Landsat data has already been acquired by multiple organizations who also freely distribute the data. If USGS attempted to charge for imagery in the archive, other organizations that currently possess the archive could provide it at lower prices or for free, undercutting any government revenue from the existing archive.

2. Users of Landsat data have been highly sensitive to price.

- Some academic, government and NGO users do not have the financial ability to pay any fee for the data and would abandon the use of any data that is not already freely available in their own or other open archives.
- Users will replace Landsat with substitutable alternatives that are free such as data from the Moderate Resolution Imaging Spectroradiometer (MODIS) or European Commission (EC) Copernicus Sentinel 2-A and –B.[4, 5] Assuming that the EC does not modify its price and use policies in response to changes in Landsat policy, charging for Landsat data would drive users of the non-thermal bands towards substituting Sentinel 2 data for Landsat and the demand for much of Landsat data would significantly diminish.
- Some of the largest users of Landsat data are U.S. Government agencies.[6] Charging them for Landsat will not generate any new revenue, but will simply shift government funds from one agency to another.
- Historically, there is evidence to suggest that if fees are increased, usage will drop significantly, as happened following the Land Remote Sensing Commercialization Act in 1984. "This resulted in exponential cost increases for Landsat data, with digital Thematic Mapper scenes costing up to US$4,400 each. At a time when computing power was increasing and the new field of GIS was budding, orders for Landsat data were decreasing – primarily due to the higher costs. These costs put Landsat data largely out of the hands of scientists working on large-scale or long-term studies, prompting some scientists to migrate to other coarser resolution datasets…"[7]

[4] Miller, H.M., Richardson, Leslie, Koontz, S.R., Loomis, John, and Koontz, Lynne, 2013, Users, uses, and value of Landsat satellite imagery—Results from the 2012 survey of users: U.S. Geological Survey Open-File Report 2013–1269, 51 p., http://dx.doi.org/10.3133/ofr20131269

[5] *Land 1-KM AVHRR Project: An Emerging Model for Earth Observations Institutions*, 16 Photogrammetric Engineering & Remote Sensing, 153. (1995).

[6] Green, Kass, Jim Plasker, Gerald Nelson, and Don Lauer. 2007. Report to the White House Office of Science and Technology Working Group on the American Society for Photogrammetry and Remote Sensing Survey on the Future of Land Imaging. Photogrammetric Engineering & Remote Sensing. pg. 5-9. Vol. 73. Number 1.

[7] Butcher, G., Owen, L., Barnes, C., *Landsat: the Cornerstone of Global Land Imaging*, https://www.gim-international.com/magazine/january-february-2019

3. Implementing a fee for Landsat data would be costly to the U.S. Government, which would incur transaction costs for managing authorized payment mechanisms to invoice, track, and process payments.

Additionally, for the business model of selling digital data to be successful, customer use must be restricted in some way, because digital data can be copied at no cost, are easily accessible across the web, and can be simultaneously consumed by multiple users without diminishing the data's value. As commercial satellite providers have demonstrated, generating revenue from the sale of digital satellite data requires that users be restricted from copying or sharing the data through some type of licensing agreement. However, because Landsat data is owned by the U.S. Government, it cannot be copyrighted and the legal mechanisms to protect its economic value are limited.[8] If the data remains free and open to some users, such as researchers or government agencies, but not to other users, such as commercial entities, it is unlikely that the U.S. Government will be able to restrict sharing of the data between non-fee paying and fee-paying users.

Finding: The LAG believes that charging a fee for Landsat data will generate little net revenue. The net revenue would potentially be less than the government costs incurred to implement the fee.

Finally, instituting a fee for Landsat data would result in severe economic impacts to the U.S. commercial satellite and value-added industries that rely on Landsat data for spectral calibration[9] or as input into their analysis products and services. As stated by the LAG in 2018, "the decision in 2008 to make Landsat data freely available to the public set global expectations for the availability of free high-quality imagery, and sparked a wave of commercial activity based on this opportunity. Commercial U.S. satellite image analysis companies Orbital Insight, Descartes Labs, SpaceKnow, GDA Corporation, Esri, and U.S. commercial satellite companies DigitalGlobe (now Maxar Technologies), Planet, AstroDigital, BlackSky and others all provide Landsat data through their platforms and offer various levels of value-added products based on free and open Landsat imagery."[10] Any fee for Landsat data will negatively impact these vibrant industries by increasing their production costs.

Finding: The LAG believes that charging a fee for Landsat data will result in negative economic impacts to the U.S. commercial remote sensing satellite and value-added industries.

Legal and Regulatory Obstacles

In 2012 the LAG produced the paper *National Geospatial Advisory Committee – Landsat Advisory Group Statement on Landsat Data Use and Charges*. One of the key findings of that report was that fee recovery for Landsat data was inconsistent with "existing OMB guidelines, Federal Law, OSTP and U.S. National Space Policy" and that imposing data charges would require regulatory and statutory revision. A current review of the relevant statutes reveals that a change in law likely would be required for any significant fee recovery of Landsat data. Specifically, the 1992 Land Remote Sensing Policy Act mandates

[8] Edwards, Gary R., *EOSAT's Approach to Protection of Proprietary Rights in Remotely Sensed Data.*
[9] The importance of Landsat for calibration purposes was demonstrated with the emergence of Mission to Planet Earth (MPE). MPE was envisioned as a long-term, integrated monitoring system comprised of satellites and other on-orbit platforms. To prepare for MPE, NASA and NOAA needed a global data set to calibrate the mission's new sensors. The then existing law required them to purchase the data from EOSAT who quoted a price of $50 million. This became a major reason the law was changed. cf. J.I. Gabrynowicz, *The Perils of* Landsat *from Grassroots to Globalization: A Comprehensive Review of US Remote Sensing Law with a Few Thoughts for the Future*, Chicago Journal of International Law (2006).
[10] See footnote 2

Landsat data be made available at no more than the cost of fulfilling a user request (COFUR) and that COFUR "shall not include any acquisition, amortization, or depreciation of capital assets originally paid for by the United States Government or other costs not specifically attributable to fulfilling user requests." The law also prohibits recovery of costs[11] "associated with providing product generation, reproduction, and distribution of unenhanced data in response to user requests." Additionally, at the time of this writing, Congress passed a number of laws that will have substantial consequences for all Federal data polices, including Landsat.[12] Further, the Office of Management and Budget has been developing a new Federal Data Strategy (Principles and Practices).[13] These laws were passed, and the OMB policy was developing, as the LAG project was concluding. Since implementation is not yet complete, the new laws and developing policy will not be specifically addressed here. As to how they will impact Landsat, this may be an appropriate subject for a follow-on study.

Finding: The LAG believes that given existing statutory and regulatory constraints, the Federal Government could not readily charge for Landsat data without substantive changes in both law and regulations.

Societal Costs and Political Considerations

Far more important than the economic and legal obstacles to charging for Landsat are the costly societal impacts of changing the current data policy. The annual societal benefit of Landsat data to U.S. users in 2011 was estimated at approximately US$1.8 billion, which is two times greater than the cost of building and launching Landsat 8 – a system that has already been in operation for five years. Much of the value stems from the free and open data policy, which allows users to access unlimited amounts of imagery and share it with others as they need at no cost.[14] Prior to the free and open data policy, research and operations were often restricted to an affordable volume of data, rather than the amount of data really needed.[15] Charging even small fees diverts customers and diminishes use. It would likely result in an immediate loss of global users and a significant decline in the amount of data downloaded to study global problems. The small net revenue produced from fees would be greatly overshadowed by the loss of societal benefits produced by free and open use of Landsat for a myriad of applications including food security, coastal monitoring, disaster response, change monitoring, forest management, crop insurance, water assessments, fisheries management and wildfire planning and response, among others.[16]

As the LAG determined in 2018, "too many critical U.S. research and operational programs rely on free and open Landsat data for the U.S. to cede its leadership in moderate resolution earth observations to

[11] 51 U.S.C. 60101

[12] https://www.congress.gov/bill/115th-congress/house-bill/4174; see, https://bipartisanpolicy.org/blog/congress-provides-new-foundation-for-evidence-based-policymaking/

[13] https://strategy.data.gov/ The draft for the Year 1 Action Plan is to be released in late spring, 2019.

[14] Miller, H.M., Richardson, Leslie, Koontz, S.R., Loomis, John, and Koontz, Lynne, 2013, Users, uses, and value of Landsat satellite imagery—Results from the 2012 survey of users: U.S. Geological Survey Open-File Report 2013–1269, 51 p., http://dx.doi.org/10.3133/ofr20131269

[15] For example, in 1990, the State of California embarked on a project to map the hardwood rangelands of the state - an area of over 40 million acres. The cost of one date of Landsat imagery for the project area exceeded $200,000 and because the cost was so high, only one set of imagery was affordable. However, a minimum of 2 dates of imagery would have resulted in more accurate maps, as the combination of leaf-on and leaf-off images is instrumental in distinguishing evergreen from deciduous tree species.

[16] To read several relevant case studies, see https://landsat.gsfc.nasa.gov/wp-content/uploads/2019/02/Case_Studies_Book2018_Landsat_Final_12x9web.pdf

the European Space Agency (ESA) Copernicus Programme Sentinel-2 satellite constellation. Maintaining U.S. homeland, food, and environmental security are all dependent upon free and open Landsat data."[17]

If users turn to Sentinel data exclusively, because Landsat data is fee-encumbered, that circumstance could undermine the benefit of easily accessible, supplemental, and reinforcing information, provided by more than one source. Because the Sentinel systems were purposefully designed to complement Landsat measurements, Landsat-8, Sentinel-2A, and Sentinel-2B together offer an average revisit interval of 2.9 days,[18] with more revisit opportunity approaching the poles and less approaching the equator. With the addition of Landsat-9, the revisit opportunity would approach 2 days.[19] For the first time, with this virtual constellation, continually monitoring resources in even the most clouded areas is possible. The combination of these U.S. and European measurements is critical to the global monitoring of water quality, food production, forest management and the impacts of disasters.

One of the elements of U.S. National Security Policy is to ensure the resilience and redundancy of such critical infrastructure. Critical infrastructure includes assets that facilitate key social and economic functions. Landsat has been evaluated to be among those assets, now strengthened by Sentinel. The utility of Landsat was assessed by the U.S. Government to be among the most valuable Earth observation data sources, behind only GPS and surface weather radars.[20]

Charging a fee for Landsat data could also result in serious international repercussions if other counties follow the United States' lead and begin charging for their moderate resolution data, with the result of even higher losses to operational and research programs. Especially worrisome is the prospect of a ripple affect into other international data sharing arrangements such as those for the sharing of weather data. Of particular importance is the international Group on Earth Observations (GEO) reliance upon Landsat data for a wide range of global and regional projects.[21]. The United States was a leader in establishing GEO and encouraging other nations and organizations in adopting a free and open access approach to remotely sensed data.[22]

An additional impact would arise from the stifling of educational programs and academic research and innovations that rely upon free and open access to Landsat imagery. Recent advancements in multi-temporal analysis, which rely on hundreds of Landsat scenes, have been made possible only as a result of the free and open data policy. Charging a fee would impact real-time international monitoring programs such as Global Forest Watch at World Resources Institute, which monitors forest harvesting worldwide, and the University of Maryland's Global Agricultural Monitoring Project which supports the crop-production estimation capabilities of USDA's Foreign Agricultural Service.

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[17] See footnote 2

[18] J. Li and D.P. Roy, "A Global Analysis of Sentinel-2A, Sentinel-2B and Landsat-8 Data Revisit Intervals and Implications for Terrestrial Monitoring" *Remote Sensing,* 9 (9), August 2017, p. 902.

[19] Michael Wulder, et al. "Current Status of Landsat Program, Science and Applications" *Remote Sensing of the Environment* Vol 225 May 2019 pp. 127-147

[20] https://landsat.gsfc.nasa.gov/landsat-and-water-using-space-to-advance-resource-solutions/
This statement reflects the information found in the "National Plan for Civil Earth Observations" Office of Science and Technology Policy, July 2014.

[21] http://www.earthobservations.org/documents/geo_xiv/GEO%20Highlights%202016-2017.pdf

[22] www.earthobservations.org

Evaluation of Fee Models for Data with the Characteristics of Landsat 8 and 9

Using the discussion above, a review of the alternatives for their viability is possible.

- *Immediately instituting a fee for all archived and future Landsat data* - is not economically viable because:
    - The archive is already in the public domain and, therefore, no consumer would pay for data from the Federal Government's archive at the USGS EROS Center.
    - Sentinel-2 data is an adequate substitution for most Landsat data uses. Therefore, a fee on future Landsat data would result in most Landsat users migrating to free and open Sentinel 2 data rather than paying for Landsat data.
- *Continuing "free and open" distribution of Landsat 8 and all previously collected and archived Landsat data, but begin charging for data collected by Landsat 9 and future Landsat missions* is also not economically viable because of the ease of substituting free Sentinel-2 data for fee-encumbered Landsat data. The European Space Agency (ESA) and the EC have made a long term commitment to Sentinel-2 data with Sentinels-2C and D in production and scheduled for launch in 2023.
- *Continuing "free and open" distribution of Landsat 8 and 9 for government and academic users, but charging commercial users* – is not economically viable as a reliable government revenue source, because the use restrictions would likely not be enforceable.
- *Continuing "free and open" distribution of Landsat 8 and all previously collected and archived Landsat data, but charging users for immediate access to future collections, allowing free and open distribution only after the delay of a specified time period* – could be economically viable if there existed a large user base with this need. However, more likely, this alternative would generate revenue from only a small set of users who require data immediately and at a frequency higher than the 5-day revisit time of the Sentinel-2 constellation. Such a fee would fall on the mostly government users of Landsat data for situational awareness, disaster response and food security. In such a scenario, this model would return to one government agency paying another government agency with no definable cost saving to the taxpayer since any fees collected would not likely offset the cost of implementing the option.
- *Continuing "free and open" distribution of all previously collected and archived Landsat data, as well as the non-thermal bands of future Landsats, but charging for access to the newly collected thermal bands.* – could be economically viable if there existed a sufficiently large user base with this need and who are satisfied with the thermal band spatial resolution. Again, such a fee would fall on the mostly government users of Landsat thermal sensing for food security and water management. Any fees collected would not likely offset the cost of implementing the option. Emerging commercial interest in thermal sensing is focusing on higher resolution collections, including use with UAS platforms.[23]

Finding: The LAG believes that the revenue obtained for charging a fee for Landsat data would not be worth the economic, legal, societal, or political costs that would be incurred, particularly given the measures that would need to be required to change applicable law and regulation or to revoke internationally lauded and followed data policy.

[23] Some research is currently underway to assess the growth of the commercial market for thermal remote sensing. A reference with minimal available information at this point in their research is https://marketresearch.biz/report/ir-thermal-imaging-systems-market/

Recommendation: The LAG recommends that the Department of the Interior not implement any fees for Landsat data with the characteristics of Landsats 8 & 9.

1.2. Charging Fees for "Enhanced" Landsat Data with Improved Spatial or Spectral resolution over Landsat 8 and 9 or for Tailored Image-collection Requests

Another fee recovery alternative considered by the LAG was charging for "enhanced"[24] products or for tasking options. Under this model, Landsat data with the characteristics of Landsat 8 and 9 would continue to be free, but the U.S. Government would charge customers for additional specifications of the desired data and/or tasking requests. These might include:

- Improved spatial, spectral, or temporal resolution
- Tailored image-collection requests

One option under this model would be for the USGS to develop a fee schedule for certain system improvements for which users may be willing to pay on a user-based agreement. Such improvements might include higher spatial or temporal resolution, or additional spectral bands. The U.S. Government would continue to launch system(s)/sensor(s) designed to meet and to exceed the spectral and spatial resolutions compatible with the current Landsat mission and continuity. The data would be separated into sets, baseline data and "enhanced" data. Any baseline imagery would remain "free and open." However, there would be a fee for requested "enhanced" imagery. For example, there could be a fee for requesting more frequent revisit over a particular area. One variation to this consideration is that the improved resolution could be available at no cost only over the United States and only to U.S. citizens.

The LAG identified a number of significant challenges associated with this model. These include:

- *Increased costs.* Significant costs could be associated with designing an equitable fee schedule for the improved data request model, creating dual (baseline and "enhanced") functionality, building a facile and agile data management infrastructure, and – most importantly - implementing an engineering architecture with any technical changes required to the satellites, sensors or ground stations to permit "tasking on demand."
- *Uncertainty.* A great deal of uncertainty exists as to how big the market might be for these improved resolution products and flexible tasking options. Another concern is how potential customers evaluate the attendant costs for special request against what baseline Landsat or other governments will be providing for free. There is considerable risk to this approach with currently little insight into the cost-benefit factors.
- *Competition with the private sector*. More importantly, under this model, the U.S. Government might be competing with the growing number of both airborne and satellite imagery commercial providers who already offer increased spatial, spectral, and temporal resolution, and permit tailored tasking options.

[24] Use of the term "enhanced" in this section is in quotes since the enhancement is not intended to imply subsequent value-adding to a baseline product, which should be a commercial activity. The enhancements are within the design of the satellite/sensor but are exercised only upon fee-encumbered request. How the Land Remote Sensing Policy Act of 1992 would apply would require some investigation. "**Title V: General Provisions** - Provides for nondiscriminatory availability of data. Requires that any unenhanced data generated by the Landsat system, or by any other land remote sensing system funded and owned by the U.S. Government, be made available, with specified exceptions, to all users on a nondiscriminatory basis."

Finding: The LAG believes that there may be an opportunity to generate revenue by selling "enhanced" imagery products and tailored tasking options from sensors onboard Landsat satellites while still making standard Landsat 8 and 9 imagery data free and openly available. However, there are apparent and significant concerns or risks that could make such an option difficult to implement.

Recommendation: The LAG recommends a more thorough review of these concerns if this approach is considered.

2. Resource Leveraging

Another option considered by the LAG is resource leveraging to mitigate costs by understanding and utilizing others' capabilities and resources. An example is considered in this section.

Landsat data stores grow each day. Customer requests have skyrocketed, especially since the "open and free" policy was adopted for Landsat imagery. (See Appendix 1 for specific details.) The infrastructure to manage that growing volume, whether as the archive or as the distribution service, requires an agile operator who can quickly adapt to the most current technologies, applications, and physical environments. That agility is not typically a hallmark characteristic of Federal agencies. Furthermore, the increasing need for sufficient space, responsive networks, and transaction services to needy customers presents itself as a costly prospect for satisfactory service. Without changing the underlying principle of "free and open" for the Landsat data itself, it might be possible to reduce operational costs by outsourcing the infrastructure, hosting, and management of the data to a third-party commercial cloud provider. The key advantage of such an implementation transfers costs to a company specifically skilled to stay abreast of rapid advances in information technology, which should facilitate modernization as part of its own business strategies and plan. This approach should improve service performance in the eyes of the Landsat customer but also allow some other tiered and priced services (e.g. high-speed data connections/transfers, bulk data downloads, Service Level Agreements (SLAs), etc.) if desired by the customer.[25]

Such a decision would not be precedent setting. For example, "NASA was a pioneer in cloud computing having established its own private cloud computing data center called Nebula in 2009 at the Ames Research Center (Ames). Nebula provided high-capacity computing and data storage services to NASA Centers, Mission Directorates, and external customers. In 2012, NASA shut down Nebula based on the results of a 5-month test that benchmarked Nebula's capabilities against those of Amazon and Microsoft. The test found that public clouds were more reliable and cost effective and offered much greater computing capacity and better IT support services than Nebula."[26]

One might argue that distribution from the USGS Earth Resources Observation and Science (EROS) Center already falls into that business model to some extent. The EROS Center processes and distributes data from both Landsat and other Earth-observing satellites and also manages an extensive archive of remotely sensed data. The site and facilities are government-owned/directed and contractor-operated – the GOCO business model. The work of EROS is carried out through a number of mission-

[25] As discussed below, in a public-private-partnership model, those tiered services could have fees that benefit the third-party provider.

[26] See: NASA Office of Inspector General Report No. IG-13-021 (Assignment No. A-12-022-00) https://oig.nasa.gov/docs/IG-13-021.pdf

support contracts with industry. The Technical Support Services Contract (TSSC) is the most significant of those contracts. Under the TSSC, contractor SGT, Inc. provides scientific, engineering, and technical support for data reception, processing, archiving, distribution, and research. In the current situation, however, most of the IT systems used are government procured. The cost of making improvements to existing government IT systems often hinders modernization, sometimes rendering a current contract operation for distribution less than optimal.

Moving from the current Government-owned, Contractor-operated (GOCO) business model, which was introduced to reduce financial costs and risks, to more dependency upon the private sector introduces other concerns. Transitioning from a GOCO business model to a Contractor-owned, Contractor-operated (COCO) business model shifts expenses from capital investment to operating costs. Such a shift could result in some cost avoidance and allow contractors, with expertise in archiving, distribution, and even processing technology, to maintain IT system currency. According to an AFCEA International[27] *Signal* article report, in 2016, "nearly three-quarters of the budget for Federal Government information technology is annually expended to keep outdated equipment running."[28] In the article, author Young poses the critical question about how new contracts might be written to assure the contractors do improve IT, as it is available, without incurring more cost than currently spent. He further described a concern voiced by those revamping the business model about how to assure the contractors are fully vested in the Federal agency's mission, strategy and success. Sustaining credibility for the contracted service in the mind of the data customer/user involves strict compliance with the Federal Risk and Authorization Management Program (FedRAMP) and the Federal Information Security Modernization Act (FISMA). In this case, DOI and NASA would need to evaluate any cyber-security risks.[29]

Finding: The LAG believes that moving from the current Government-owned, Contractor-operated (GOCO) business model, to a Contractor-owned, Contractor-operated (COCO) business model could provide for more efficient delivery of Landsat imagery and provision of data management services at lower costs.

Recommendation: The LAG recommends that further research is needed to examine the benefits and costs of transitioning from GOCO to COCO at the USGS Earth Resources Observation and Science (EROS) Center.

3. Public Private Partnerships (PPPs)

Public Private Partnerships (PPP) are another alternative considered by the LAG for generating revenue and/or offsetting costs for Landsat. A PPP involves government and industry working together on a project that provides broad benefits to a society. PPPs are often used in other public infrastructure projects, such as for roads or energy. Some PPPs have been used for satellite development and operation.

Several benefits of PPPs accrue to the involved government entities. One of the primary benefits is some cost reduction for expensive projects because the government does not have to invest as much capital

[27] In September 2018, the Armed Forces Communication and Electronics Association changed its official name to AFCEA International.
[28] Young, D., "Contractor-Owned Systems Could Open the Door to Innovation for Government", Signal, July 1, 2016.
[29] https://digitalguardian.com/blog/what-fisma-compliance-fisma-definition-requirements-penalties-and-more

as it would if it were to take on the project alone. A related benefit for governments is the transfer of some of the risks associated with a significant project to an industry partner. In some instances, a PPP also will result in the project being completed more quickly and for less money expended by both parties.

The industry partner within the PPP contributes resources including capital, technology and/or manpower. Provision of those resources comes with the expectation that it will be sufficient to generate enough revenue to offset the cost of the investment and to make an acceptable return. That means there are identifiable customers willing to pay for the products or services associated with the project. The amount of capital the private sector will be willing to contribute will depend upon a number of factors, including the potential market size, whether there are competitors, and whether there is confidence in some viable business model.

Key challenges associated with putting together a PPP will apply to developing a PPP involving Landsat. These include:

- Differing Perspectives – Government and industry often have different views:
    - how much capital (and what type) from each party
    - how to allocate the risk if the project takes longer than expected or fails to generate the expected revenue
    - which party owns the intellectual property rights
    - what is a proper return on investment for industry
- Complexity – A properly constructed PPP must document agreements on:
    - governance
    - structure
    - funding
    - economic value prospectus
    - intellectual property rights
    - allocation of risk

  Given the importance of Landsat continuity and community dependence upon quality calibrations, another critical issue is what are the parties' respective rights and responsibilities upon termination of the PPP agreement.
- Market challenges – Revenue generation for any of the Landsat fee alternatives described above underscores the uncertainty about attracting the participation of a private sector partner. Charging for the Landsat data that is currently made available for free may not result in much revenue. Although reportedly expanding, the overall market for remote sensing products and services may not be robust enough for a private partner to develop add on products and/or services that generate sufficient ROI to permit traditional Landsat imagery to be made available at no cost.
- Cultural Challenges – A private sector partner working on Landsat could modify the legacy of the Landsat program and disrupt standard operating procedures in the approach to establishing a business case. Those changes could be perceived as disadvantageous to many users. A PPP might also require refocusing USGS government-employee jobs from legacy roles to increasingly value-added services. Depending upon the implementation that could escalate or mitigate concerns about government competing with industry.
- Legal/Regulatory Challenges – Government agencies generally need legal authority to enter into PPPs. As a result, additional Congressional authority may be needed in order to implement certain PPP options for the Landsat program including amending the Land Remote Sensing Policy Act.

Currently data policy for a satellite partly funded by tax dollars and partly funded by private dollars is regulated.[30] The regulations take into account the percentage of funds provided by the public and private parties and that determines the data policy on a case-by-case basis. How much data can be sold at market price and how much data has to be distributed pursuant to the nondiscriminatory access policy should be known up front to determine if a particular venture will be profitable.

Based upon these factors, the LAG identified three possible options under the PPP model that might be worth further exploration.[31] These are:

1. PPP for Higher Resolution Landsat Satellites – Government and industry could partner to build and operate future Landsat missions with a capability to collect higher resolution imagery than is currently collected. This imagery could be resampled and continue to be made available to all users for free. The industry partner could then sell the higher resolution imagery under restrictive licenses to users who can access or download the imagery for a fee.

   This option was discussed in more detail in a previous LAG report.[32] According to the report, "[t]he contractor's [i.e. private partner] system could exceed Landsat requirements in any of a number of ways (e.g., higher spatial resolution, more spectral coverage, more temporal revisit, higher calibration standards, spatial accuracy, etc.). For example, the Landsat requirement for spatial resolution could be 30 meters with the contractor superior spatial resolution at 10 meters or higher. The contractor would have commercial rights to the full-capability data, which it could monetize because what NASA/USGS shared freely was fundamentally a different product and so would not cannibalize the commercialization opportunity."[33]

   This model is predicated on the assumption that the demand for the superior data, that is differentiated from the freely distributed Landsat data, is valued enough by the market to enable the contractor to earn a satisfactory return on its investment. The model was considered in 2002-2003 in connection with the Landsat Data Continuity Mission (LDCM). However, the approach failed because NASA and potential partners were unable to come to agreement on the economic terms and allocation of risk. Circumstances, markets, and technologies have changed which may make this model more viable. In addition, there are more potential partners that might be willing to participate.

2. PPP for Commercial Sales – Government and industry could partner to build and operate future Landsat missions that would continue to make imagery available to government agencies, academic educators and researchers, and others (complying with yet-to-be-determined criteria) for no cost, but would charge for commercial users. Under this scenario, commercial customers would pay a license fee to the private industry partner and would accept the attendant licensing restrictions.

[30] 15 CFR Part 960.
[31] A number of the options discussed are currently not permitted under existing law particularly as they relate to the nondiscriminatory access policy. See, 51 USC 60141. Therefore, change in existing law will be necessary for some of these options.
[32] See footnote 2.
[33] Ibid.

The Center for Space Policy and Strategy released a policy paper, "Public-Private Partnerships: Stimulating Innovation in the Space Sector", in April 2018, that described a similar model being used by for TerraSAR-X/TanDEM-X – the German radar satellite constellation. In that case "[t]he government partner, DLR, provides SAR [synthetic aperture] data to the scientific community, while the commercial partner, Airbus, exclusively distributes to the commercial sector through its GEO-Information division – including providing value-added products including 3D urban simulations and Digital Elevation Models."[34]

Another example of this model is the arrangement between DLR and Teledyne Brown to host DLR's DESIS hyperspectral sensor on the company's MUSES platform on the International Space Station. The images collected by DESIS will be available through partnerships with DLR, NASA, the Alabama Remote Sensing Consortium and commercially available through Teledyne Brown.[35]

3. PPP to Reduce Cost of Distribution of Imagery – Government and industry could partner to reduce the cost of distribution, increase usage and create a measurable revenue stream for the industry provider from commercial users of the higher value data. (This PPP model has similarities but also differences from the COCO model described in Section 2 above.) SLAs lay down the terms and conditions of transfer of service or commodity or data from one party to another. Today's distribution costs for Landsat are affected by the data requesters' high expectation of reliable and prompt service from USGS EROS Center and the embedded SLAs in place with contracted support. Perhaps a PPP could implement a lower cost approach that is appropriately responsive with more flexibility.

   Additionally, it can be envisioned that more users will wish to run processes against the Landsat data directly on the cloud environments without downloading the data, which could add layers of SLAs as well as increased costs to the Landsat customer servicing model. It is expected that the USGS would not be able to provide cloud computing resources but would be responsible for all data processing into the standard USGS defined products and remain the authoritative source for users to download data from.

   A possible partnership could foresee the use of commercial cloud providers taking on the role of providing cloud processing capabilities, large volume data download and collecting fees from commercial organizations for use of the higher value data that is less than two (2) weeks (or a predefined time frame) old. In such a scenario Landsat would still be distributed free by USGS in two ways:
   - Through a free and Open Data Hub that enables anyone to download scenes that are over two (2) weeks old. This would enable any users to download the data for free, but no guarantees would be provided on the timing availability of the data, particularly during periods of significant load. This would eliminate the SLAs currently in place through the USGS EROS Center for anyone using the Open Data Hub.
   - A user-limited number of cloud providers, partnering with the government through PPPs, would provide a high level of service to enable each customer to download one copy of the

[34]Public-Private Partnerships: Stimulating Innovation in the Space Sector, Center for Space Policy and Research (April 2018) (https://aerospace.org/sites/default/files/2018-06/Partnerships_Rev_5-4-18.pdf)
[35] https://hyspiri.jpl.nasa.gov/downloads/2016_Symposium/day2/7-4_Teledyne_DESIS_Spectrometer_on_the_ISS-based_MUSES_Platform.pdf

data immediately after its availability. These cloud providers would then provide subsequent free access to the data, but could charge for additional computing and egress costs. All non-U.S. Government organizations would be charged a fee to access data that is less than two (2) weeks old. This fee could be relatively low (possibly $1 per unit of delivery per organization). Organizations accessing the data could create derived products but not resell/license the new multispectral imagery. The access charge would be collected by the cloud provider and paid back to a fund to help offset costs of the Landsat program. Cloud providers would also need to report download and computing usage of the data. These reports could be used to better evaluate usage, trends and value.

The cloud providers would gain the benefit of users wanting to compute and process on their clouds which they could charge for at their standard compute rates. Cloud providers could charge standard egress cost for users to download the data out of the cloud region in which it is hosted. The advantages of this method are that:

- The Landsat data remains free and open for all data over two (2) weeks old and all U.S. Government usage. Users could download from USGS or from one of the cloud providers. Processing large data sets such as Analysis Ready Data would become more achievable enabling greater usage.
- The distribution and storage cost for USGS would be reduced due to lower service level requirements. Most academic, research science, or planning use of the data should not be affected by the two (2) week access delay. However, for as low cost as possible, the access delay can be eliminated using the cloud providers.
- Cloud providers would take up the cost of hosting the imagery in return for gaining revenue from providing computing power to process the data. There would be no monopoly by any cloud provider, so cloud compute costs would expect to be kept low.

There are disadvantages that too should be included in this examination of this third PPP option.

- Some users, who need imagery immediately for disaster response (such as for disaster response or food security) may lack funds to purchase the most current collections and will be unnecessarily penalized.
- As with some of the earlier examination of the fee alternatives, users may switch to Sentinel, unless thermal data is required, rather than accept any possible delay.
- If most users do not require immediately the most current collection, then it is not clear that the revenue stream is strong enough for a PPP.

Based upon these factors and the three examples provided, the LAG recommends further research on the viability of a PPP model for Landsat. Such research should include dialogue with industry as early as possible to make sure its concerns are considered.

Finding: The LAG believes a Public Private Partnership could allow the U.S. Government to benefit from some of the efficiencies of the private sector industry, while maintaining Landsat continuity. It could also preserve public/open availability of Landsat-quality data. However, this approach depends upon the ability of private industry to develop and implement a successful business model and upon any legal changes required including amending the Land Remote Sensing Policy Act.

Recommendation: The LAG recommends that further research is needed to determine if a sufficient business case exists and what legal changes are required to support exploration of the creation of public-private partnership(s).

4. Insight

The Landsat Advisory Group members have conducted several teleconferences and exchanged numerous emails over the last several months, grappling with the thorny question about the acceptability of returning to an era when Landsat data was not "free and open" and when use of this remarkable source of Earth information was limited by budget barriers. As the history in Appendix 1 shares, the explosive growth of use and the remarkable benefits from the varied applications since 2008 is formidable evidence that access to the data should never again be limited. Members of the Landsat Science Team[36] published a paper in February 2019 on the "Benefits of the free and open Landsat data policy" reinforcing the LAG's recommendations. "Based upon insights gleaned from our participation on the USGS-NASA Landsat Science Team, we assert that the free and open data policy is key to the ongoing success of the Landsat program. … The U.S. is a world leader in the provision of Earth Observation remote sensing data, science and applications, and the free and open Landsat data policy underpins and maintains this leadership position."[37]

The LAG's intent was to present as objective as possible an examination of several alternatives for generating revenue or avoiding costs. LAG members are all supportive of free and open Landsat data continuity. The LAG moreover believes that, given the findings in this report, a more fruitful study would be to analyze how the costs of building and launching Landsat sensors could be reduced, rather than focusing on cost sharing of operations. LAG members are optimistic that through the application of newer technologies and the use of partnerships, affordability will improve. This is consistent with the LAG recommendation made in April of 2018, "The U.S. Government should aggressively investigate rapidly emerging and increasingly proven technologies which could greatly reduce the cost of Landsat missions."[38]

Acknowledgments

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[36] The Landsat Science Team provides technical and scientific input to USGS and NASA on issues critical to the success of the Landsat program, and to ensure that data from future missions such as Landsat 9 are integrated into the overall Landsat record. The team consist of USGS and NASA scientists and engineers, external scientists, engineers, and application specialists, representing industry and university research initiatives.

[37] sciencedirect.com/science/article/pii/S0034425719300719 (Feb 2019)

[38] See footnote 2

Appendix 1: Background

The evolution and history of Landsat technologies and data policies are complex. They also provide important insights as to how users might respond to future changes.

NASA launched the first Landsat satellite in 1972. The data's spatial resolution was coarse, 80 meters, and included four bands: green, red, and two infrared. Technological barriers slowed use of the imagery because the knowledge base was small; little image processing software existed; and, files were huge for that time, requiring mainframe computers. Most users were academic scientists and government agencies with access to mainframe computers capable of processing the data. Landsats 2 and 3 capabilities were similar to Landsat 1.

The responsibility for Landsat was moved from NASA to NOAA in 1979. Landsat 4 was launched in 1982. Landsat 5 was launched in 1984. Spatial resolution was increased to 30m and spectral resolution was expanded to seven bands, adding two middle infrared at 30 meters and one thermal band at 120m.

In 1984, Congress passed the Land Remote Sensing Commercialization Act that directed NOAA to migrate Landsat imagery data distribution from the Federal Government to the private sector. The intention was to have revenue from commercial imagery sales support the continuation of the Landsat program. A commercial company – EOSAT – was formed and the price of Landsat data was increased from US$2800 per scene under NOAA to US$6000 per scene. To protect potential sales to entities beyond the original licensee, customers were prohibited from sharing the data. (Edwards, Gary R., *EOSAT's Approach to Protection of Proprietary Rights in Remotely Sensed Data.)* The demand for imagery sharply declined as did Landsat research and innovation (Draeger et al, 1997).

For a variety of reasons (Gabrynowicz, 2006), Congress passed the Land Remote Sensing Policy Act (Public Law 102–555) in 1992. It repealed the 1984 law and ended Landsat commercialization. Landsat 6 failed to reach orbit. The USGS was directed to take over distribution of Landsat 7 imagery when it was launched. Imagery had to be distributed with no use restrictions and priced at no more than the cost of fulfilling user requests. Landsat 7 was successfully launched in April of 1999. The USGS set the per scene price at US$600 and drastically lowered the cost for foreign ground stations to download imagery. In response to the lower price, EOSAT was forced to reduce its price for Landsat 4 and 5 imagery. Eventually, unable to run Landsats 4 and 5 profitably with reduced revenues, the company returned its distribution rights to the Federal Government in 2002. The lower price and unrestricted licensing for all Landsat imagery data resulted in a dramatic increase in the operational use of Landsat imagery. However, government revenue from image sales only grew from US$4 million in 1999 to US$11 million in 2002.

Imagery access was still cumbersome and slow, requiring the manual ordering and writing of CDs. Significant declines in storage costs, increased processing power, innovative applications, and broader bandwidth soon greatly reduced the cost of processing, storing and distributing Landsat imagery.

From 1972 to 2008, no more than 3000 Landsat images were ever sold in a given month (Wulder et al., 2012). In 2008 USGS made new collections of Landsat data free and accessible for download from the web. By 2009, the archive was also available on the web. Nearly one million images were downloaded in 2009, the first full year of free and open access. The intention was that this "open data" policy would spur broader use of the imagery thereby increasing its societal and economic benefits. The plan was a

huge success, as the use of Landsat imagery sky-rocketed from 20,000 scenes to 5,000,000 scenes a year in 2011 (Figure 1). Commercial companies such as Google, Esri, and Amazon started hosting Landsat data and offered processing services that further increased global access to the data.

Landsat 8 was launched in 2013 with 15m spatial resolution of its panchromatic band, 30m resolution of the seven optical, near and middle infrared bands, and 100m resolution of its two thermal bands. With two Landsat systems (7 and 8) offering free and open data with 8-day revisit times, user requests soared. Figure 1 displays how many times Landsat scenes have been downloaded since the archive was opened in December 2008. As of August 9, 2018, Landsat scenes had been downloaded from USGS more than 80 million times. This number does not include the ballooning free and open use of the Landsat data accessible in the cloud through commercial web sites such as Google Earth Engine and ArcGIS online.

Access to free and open moderate resolution global imagery was further enhanced in 2015 and 2017 with the successful launches of Europe's Copernicus Sentinel 2A and 2B. These two satellites collect data with spectral resolutions specifically designed to be compatible with Landsat (Figure 2), and are also available at no cost and with use terms similar to Landsat's.

In 2015, 2016, and 2017 Congress passed the Administration's budgets that established and funded the joint NASA and USGS Sustainable Land Imaging Program for investments in technology and innovation to ensure a world class land imaging program for the next 25 years. The budgets included funding for NASA to build and launch, and USGS to manage Landsat 9 (currently scheduled to launch in late 2020) as a rebuild of Landsat 8. The budgets also called for instrument reduction studies, business model studies and other technology investigations to reduce cost and risk in next-generation Landsat missions.

With this Congressional and Administrative direction, a program to ensure continuity in Landsat observations was finally established. The strong Congressional and Administrative support of Landsat continuity is primarily the result of the vast increase in access to and use of Landsat data made possible by the 2008 decision to make Landsat data free, open and accessible on the web. The constituency for the data has grown from a narrow group of government scientists and academicians to a broad base of global operational agencies, NGOs, private companies, and citizen scientists.[39]

[39] Butcher, G., Owen, L., Barnes, C., *Landsat: the Cornerstone of Global Land Imaging*, https://www.gim-international.com/magazine/january-february-2019

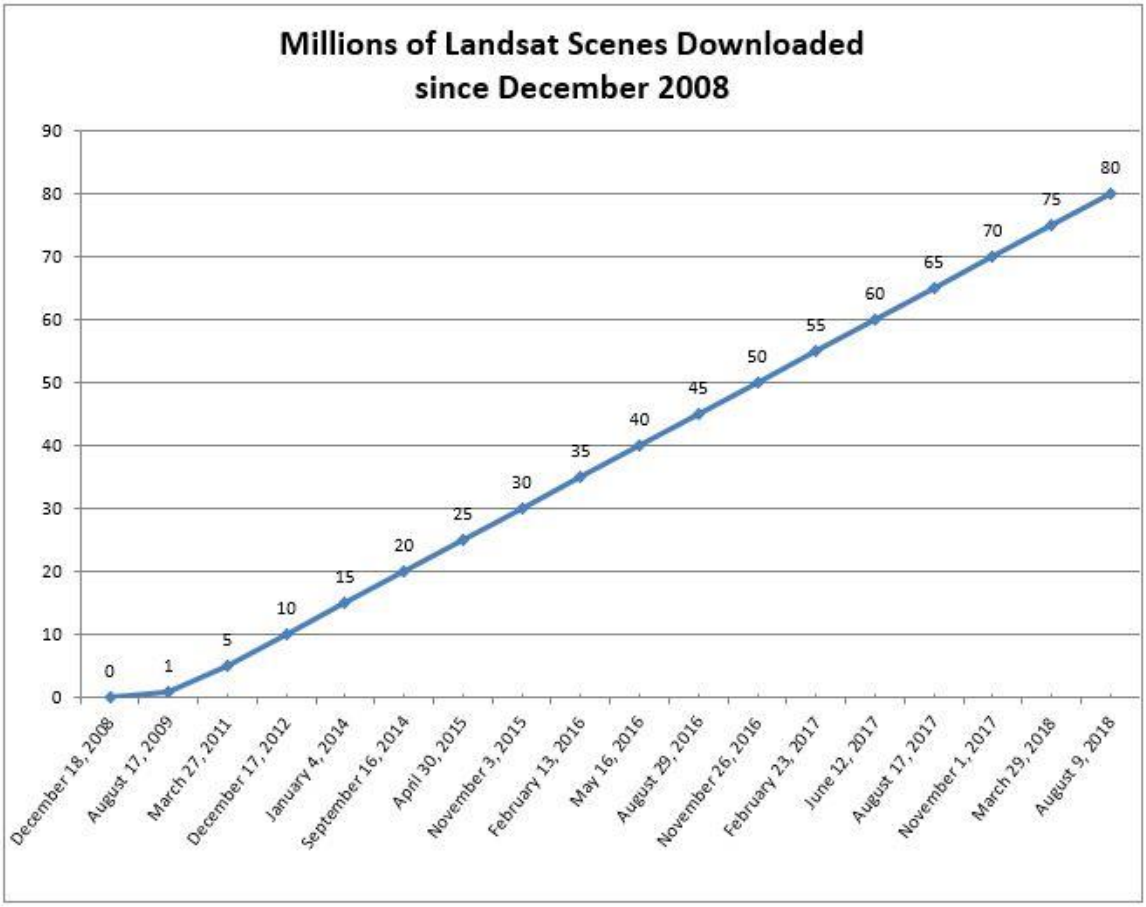

Figure 1. Use of Landsat imagery. Source: USGS and NASA

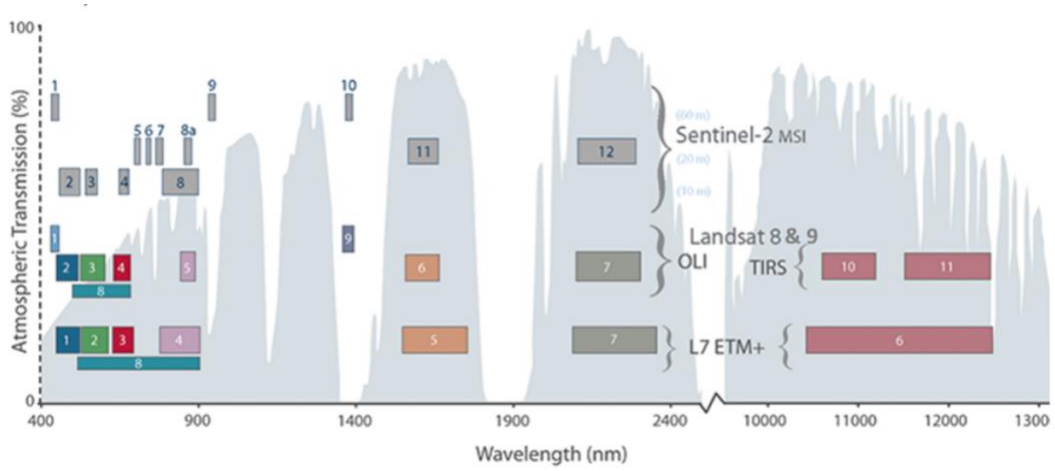

Figure 2. Comparison spectral resolution of Landsats 7, 8 & 9 versus Sentinel 2A & 2B. Source: USGS and NASA.

Appendix 2: Feedback provided by users

On June 2018, the U.S. Geological Survey posted information on-line for the Landsat data user community providing awareness on the study the Department of Interior had requested the Landsat Advisory Group (LAG) to undertake.[40] The site provided a synopsis of frequently-asked-questions and an e-mail address, Landsatdatapolicy@usgs.gov , where users have been able to submit comments expressing their views and concerns.

To date, USGS has received nearly 40 e-mails representing comments and input from a national and international cross section of user groups of Landsat data. These inputs provide a view into the concerns felt by this broad user community and the impact that a change in the free and open data policy could have. The following user groups are represented in the comments received:

- U.S. State and local government entities
- U.S. and Foreign Academia
- Doctorate and Graduate-level students (U.S. and Foreign)
- International User Community groups
- Non-Profit groups
- Industry
- Private Citizens

International groups have recognized the U.S. Government's decision to provide free and open access to Landsat data as a "landmark decision whose far-reaching impact saw numerous countries follow their example in also adopting a free and open data policy."[41] Reversing such a global precedent-setting decision could influence other countries to revisit their data policies, something that could severely limit access to valuable authoritative data, crippling worldwide advancement on Earth Science research as a whole and the use of Earth Observation data to create value added services for a global community.

The government-related entities (state, regional, and local) that provided comments discussed how they use Landsat data to assess and monitor natural resources (i.e. water, land, forest, agriculture, etc.) with limited or no funding for data acquisition. A change in the free and open data policy will impact the services they provide to their residents and any economic gains realized by more efficient monitoring and management of natural resources.

The free and open data policy enacted in 2008 has given growth to a burgeoning commercial industry, mainly small and medium sized businesses, that are the engine for innovation and economic growth within the United States. The well-characterized nature of Landsat data is recognized as a "gold standard" global data set that has enabled cross calibration of complementary missions from small satellite commercial constellations fueled by private sector investment. Many companies that employ free civil data in the development of their commercial solutions also supply data and services for humanitarian organizations in support of humanitarian assistance and disaster relief efforts.

From an academic research and education perspective, many of the comments from this user base talked to the extensive research that has been fueled since Landsat's free and open data policy was enacted in 2008. The highly calibrated global dataset, with a deep archive of over forty years has been a key data source that has enabled research across a number of topical areas, and has been used by a

[40] https://www.usgs.gov/center-news/landsat-advisory-group-undertakes-a-landsat-cost-recovery-study
[41] Letter submitted by the Committee on Earth Observation Satellites (CEOS) dated May 18, 2018.

multitude of undergraduate, graduate, and doctorate level students within the United States and across the globe ensuring a well-trained talent pool.

Finally, private citizens have also gained from freely available Landsat imagery. One comment received talked how a citizen had employed Landsat imagery available via Google Earth to "determine the precise contours of a wildfire near my family when public officials could not give us real-time information."[42]

Beyond the comments received by USGS since this study was announced, a number of articles have been published in trade publications and professional technical journals, highlighting the benefits of free and open data policy. Some are cited below.[43] Likewise, users have also taken to social media platforms to share their views, many discussing how research they have conducted would be impossible if they would have to pay for Landsat data.

[42] E-mail received from a private citizen for "public comment" dated September 8, 2018.

[43] Borowitz, M., 2019. "Government Data, Commercial Cloud: Will Public Access Suffer?" *Science*, 363 (6427), pp. 588-589.

Buchanan, G., Beresford, A., Hebblewhite, M., Escobedo, F., et al., 2018. "Free Satellite Data Key to Conservation." *Science*, 361 (6398), pp. 139-140.

Popkin, G., 2018. "US Government Reviews Data Fees." *Nature*, 556, pp. 417-418.

Wulder, M., Loveland, T., Roy, D., Crawford, C., Masek, J., Woodcock, C., et al., 2019. "Current Status of Landsat Program, Science, and Applications." *Remote Sensing of Environment*, 225, pp. 127-147.

Zhu, Z., "The U.S. Government Might Charge for Satellite Data Again – Here's Why That Would Be a Big Mistake." *Phys.org* <http://phys.org/>, 8 March 2019, https://phys.org/news/2019-03-satellite-big.html.

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