

Remote Monitoring of Conservation Easements

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Executive Summary

The objective of this report is to detail how land trusts across the country are incorporating remotely sensed data into easement compliance monitoring strategies and to share this information with the land trust community. Our approach was to conduct phone and in-person interviews with land trust practitioners throughout the United States who have implemented remote monitoring to 1) identify the types of data and methods that are currently in use in land trust organizations, and 2) understand the benefits, challenges, and best practices in the use of these technologies from the practical experiences of these organizations.

Findings from this study reflect that land trusts are using a variety of different approaches and remotely sensed data types, including in-person airborne flights, digital airborne imagery, satellite imagery, and imagery captured using unmanned aerial vehicles (UAVs). The decision of which type of imagery is best suited for a particular organization depends on a number of considerations, including the spatial resolution and availability of imagery that can detect fine-scale easement violations. Land trusts make trade-offs between data cost, availability, and spatial resolution. The majority of the 17 organizations who contributed to this study utilize aerial imagery as a supplement to on-the-ground visits which they perform at each property annually. Of the land trusts interviewed, four organizations have developed remote monitoring protocols that substitute remote image assessment for a portion of annual site visits.

There was general consensus among the interviewees that the types of sites that most benefit from remote monitoring are medium to large properties that are difficult to access due to location, topography, or other factors which have a high cost in terms of staff time and resources for on-the-ground visits. An important step in determining what sites might be suitable for remote monitoring involves the consideration of what allowed and prohibited uses and activities are outlined in the easement terms and a determination of what spatial resolution would be required to detect these changes. For organizations that have mostly smaller properties that are easy for staff to drive to and visit on the ground, there may be little benefit to developing a remote monitoring protocol.

Land trusts in this study noted that the benefits of incorporating remote monitoring on suitable properties outweigh the challenges. A main finding from this study is that on-the-ground and remote monitoring are **complementary** approaches. Remote monitoring does not eliminate the need for field visits, but it can improve the quality of easement monitoring overall. Even for organizations who visit each property on the ground every year, the ability to enhance these visits by including an assessment of remote imagery to help guide time spent in the field results in a valuable cost savings through reduced staff time and in better monitoring outcomes. During these interviews there were several

examples of violations that were missed during on-site visits which were subsequently captured through assessment of remotely sensed imagery.

The increased efficiency in staff time found with remote monitoring systems made more time available for important stewardship and conservation activities. As remotely sensed image availability, spatial resolution, and accessibility continue to improve, the potential cost savings is significant for organizations on a budget.

We have learned that there is no single monitoring solution that is best for all land trusts, all properties, or in all years. Key challenges to implementing remote monitoring include the investment of time and resources needed to get started. High resolution imagery from either airborne flights or satellite providers can be expensive, particularly when a specific time window is required for imaging. Data size is often large, so data storage, processing, hosting, sharing, and management can be a challenge for organizations. In addition, some types of easement violations might require ground visits to assess, particularly those occurring under canopy cover or significantly below the pixel resolution.

This report offers recommendations intended to help land trusts begin to navigate some of the choices that need to be made to implement an efficient remote monitoring system, including:

- Explore free, local, and state resources
- Assess easement properties, terms, and resources
- Consider what type of imagery would best meet organization needs

The use of remotely sensed data to augment on-the-ground monitoring programs has resulted in increased efficiency in staff time and therefore reduced cost in addition to improving the quality of monitoring. It is hoped that this report and the experiences of other organizations will be relevant to land trusts who are already using or considering the use of remotely sensed data to complement on-the-ground monitoring of conservation areas.

Introduction

The [Land Trust Alliance](#) (LTA) publishes the Land Trust Standards and Practices (the Standards), technical and ethical guidelines on how to responsibly manage land trusts. LTA member land trusts are required to follow these standards as guiding principles that help to establish and support public confidence in land conservation. An important requirement of this guidance is that every conservation easement property be monitored to ensure compliance with easement terms each calendar year. The Standards support the use of aerial monitoring as a method of inspecting properties, with on-the-ground monitoring required at least once every five years.

In partnership with the California chapter of The Nature Conservancy (TNC), UC Berkeley's Geospatial Innovation Facility (GIF) investigated the current use of aerial imagery and techniques to aid or supplant on-the-ground monitoring. For the purposes of this report, the terms "aerial imagery" and "remotely sensed imagery" are used interchangeably and refer to a suite of technologies including in-person airborne flights, digital airborne imagery, satellite imagery, and imagery captured using unmanned aerial vehicles (UAVs).

This study has found that there is a great deal of interest among land trust organizations regarding the use of remotely sensed data as an effective and efficient component of easement monitoring systems and programs. Remotely sensed image availability and accessibility is rapidly improving, and temporal and spatial resolutions are becoming increasingly fine-scale. Advanced image analysis techniques involving machine learning and automated anomaly detection offer promising new strategies to increase the efficiency of traditional "boots-on-the-ground" monitoring.

Despite these advances, land trusts and other conservations organizations have found significant obstacles to incorporating image data into monitoring programs. Key challenges are related to image cost, availability, accessibility, and limitations in temporal and spatial resolutions. Easement compliance monitoring has specific requirements for annual monitoring, and it may be difficult to acquire free or low-cost imagery available during the ideal monitoring time or within the required calendar year. While it is possible to task high-resolution satellites or aircraft to capture data when and where it is needed, that service is often cost-prohibitive for conservation organizations.

The type of restrictions typically used in conservation easement properties determines the spatial resolution required for detecting potential non-compliance issues. Easement terms such as restrictions on new buildings, new roads or trails, structural changes, mining or drilling, and forest harvest activities may be readily visible on moderate or high-resolution imagery. Other types of violations such as stream crossings under tree canopy, new fence lines, or trash dumping activities may be harder to detect with remotely sensed imagery. An important step in determining what sites might be suitable for remote monitoring involves the consideration of what allowed and prohibited uses and activities are outlined in the easement terms and a determination of what spatial resolution would be required to detect these changes. An additional consideration is an organization's tolerance of the risk of not detecting a violation of terms.

The purpose of this study was to understand how land trusts across the country are incorporating remotely sensed data into effective easement compliance monitoring strategies and to share this information back to the broader community. We conducted phone and in-person interviews with land trust practitioners throughout the United States (and one participant in Canada) who have tested and/or

adopted remote sensing imagery to aid in annual monitoring of easement properties. These interviews reveal a wide range of options and methods being used to support compliance assessment. Initial findings on best practices and lessons learned from this study were presented by our partners at TNC at the Land Trust Alliance (LTA) Rally in a session titled “Remote Property Monitoring: Re-imagining Annual Compliance Inspections” in North Carolina, October 19, 2019.

Background

To identify industry standards and practices in the use of aerial or remote imagery for conservation monitoring, we performed in-depth interviews of 17 different organizations that are incorporating some type of imagery into their monitoring. Interview questions were designed to gather information on organization’s past experience with using remote monitoring, information on the challenges and benefits of using those techniques, and discussion of the current and future plans around use of remote sensing technology.

Out of the organizations that took part in this study, 15 were accredited land trusts and the other 2 groups work closely with land trusts and provided valuable connections and insights (i.e. Chesapeake Conservancy and GreenInfo Network). An initial literature and white paper review was used to generate a list of potential interview subjects who had spoken about or published on their work. This list of potential interview subjects was contacted and those who responded were included in the first round of interviews. Each person or organization we contacted was asked to recommend other organizations or practitioners who might also be working with aerial monitoring. This snowball sampling approach resulted in additional organizations to invite to participate in this study. Participant organizations span different geographic regions within the US (and one in Canada) and a range of sizes from small land trusts to large operations.

These findings should be relevant to other land trusts and related organizations and non-profits who are already using or considering the use of remotely sensed data to complement on-the-ground monitoring of conservation areas. The study goals were to 1) identify the types of data and methods that are currently in use in land trust organizations, and 2) understand the benefits, challenges, and best practices in the use of these technologies from the practical experiences of these organizations. The study can help build a community of practice and guide land trusts who may be just getting started with remote monitoring.

Remotely Sensed Imagery

Remotely sensed data is becoming increasingly important to land conservation efforts as spectral and spatial resolution continuously improve. While this document is not intended to be a primer on remotely sensed data, it is valuable to understand some of the key attributes of digital imagery. A few helpful terms include:

Spatial resolution: A measure of the finest level of ground detail captured in an image, or pixel size. Commonly used descriptions: moderate (30 m – 5 m), high (5 m – 1 m), and very high (1 m – .3 m) resolution. The size of features or objects on the ground that need to be identified for compliance monitoring determines the optimal spatial resolution for a project.

Spectral resolution: Number and characteristics of spectral bands or wavelengths captured in an image. Increased spectral resolution often allows for more detailed identification of landscape and vegetation characteristics. For example, vegetation health studies are improved with imagery containing infrared and additional spectral bands.

Temporal resolution: How frequently coverage of a particular area of the earth is available. For satellite imagery, each satellite follows a specific trajectory which allows repeat coverage over an individual location within a certain number of days (i.e. Landsat satellites have a temporal resolution, or repeat cycle, of 16 days). High-resolution satellites and airborne flights can be tasked or scheduled on-demand to meet required acquisition specifications.

Orthorectification: Processing required to correct raw imagery for terrain distortions to ensure that pixels are accurately georeferenced and aligned correctly on the ground. This process defines the spatial accuracy of a product, and is required for proper overlay with other map layers within GIS systems.

Findings from this study reflect that land trusts are using a variety of different approaches and remotely sensed data. The decision of which type of imagery is best suited for a particular organization depends on a number of considerations, including the spatial resolution and availability of imagery that detect fine-scale easement violations. Land trusts make trade-offs between data cost, availability, and spatial resolution as summarized in the following table.

AERIAL IMAGERY SOURCE	COST	AVAILABILITY	SPATIAL RESOLUTION	ORTHORECTIFIED	DATA SOURCE
Airborne Imagery					
In-Person Airborne Flights	Low	On-demand	High	No	Local Pilot
Digital Airborne Imagery: Tasked	High	On-demand	High/ Very High	Usually	Private Companies
Digital Airborne Imagery: Archived	Free	Varies	High	Yes	NAIP
Unmanned Aerial Vehicles	Varies	On-demand	High/ Very High	Specialized software required	In-house or Local Provider
Satellite Imagery					
Moderate Resolution	Free	Frequent	Moderate	Yes	Landsat or Sentinel
High Resolution: Archived	Moderate	Low/varies	High	Optional at additional cost	Private Companies
High Resolution: Tasked	High	On-demand	High/ Very High	Optional at additional cost	Private Companies
High Resolution: Service	Low/varies	Low/varies	High	Varies	Maxar, Planet
Additional Sources					
Google Earth	Free	Varies	Varies	Varies	Aggregated from various sources

Additional details regarding the advantages and disadvantages of the common sources of data are included below:

Airborne Imagery

In-Person Airborne Flights: Traditional approach of hiring a plane or helicopter to fly over properties, typically taking photographs out the window of the aircraft. Frequently involves stewardship staff accompanying the flight to record notes and photographs. Several organizations included in this survey have used this methodology in the past but most are currently using other technologies and would not recommend this as a monitoring approach in the future.

- **Advantages:** usually fairly cost effective depending on local resources, can choose when and where to fly.
- **Disadvantages:** Significant time needs to be invested in planning such flights, including preparation of paper maps, GPS units, camera, etc. In addition, the quality of the imagery is usually not very good and is typically not orthorectified, so cannot be used directly within GIS software.
- **Additional Considerations:** The relationship between individual pilots or companies with the land trust is a critical component. For example, one land trust in our study has been working with a pilot for many years and is very satisfied with this system. The pilot also performs the analysis by reviewing the aerial photos and delivering maps that highlight areas of concern that should be checked in the field. Stewardship do not need to accompany the flight, which also reduces staff time needed for monitoring.

Digital Airborne Imagery (Tasked): Typically, local to national private companies who fly airplanes equipped with high quality imaging systems able to capture orthorectified digital imagery on-demand.

- **Advantages:** Flight schedules are arranged with providers so users can control when and where to fly so imagery can be tasked and flown on demand. Depending on provider and funding available, this can be extremely high-quality data. Very high resolution (<1 m) orthorectified imagery is possible. Providers can also include additional spectral information such as hyperspectral and/or Lidar sensors. High quality digital imagery can be suitable for advanced image analysis such as change detection and vegetation health studies.
- **Disadvantages:** Relatively expensive option, depending on the provider's pricing structure. However, this option may be price competitive compared to satellite imagery. In addition, there is a critical economy of scale with airborne imagery. Airborne imagery can be expensive for small areas but can be very cost effective for larger areas.
- **Additional Considerations:** Digital airborne imagery typically generates large amounts of data so data storage, processing, hosting, and sharing can be a challenge.

Digital Airborne Imagery (Archived): In the United States, archived digital airborne imagery is available at no cost through the [National Agriculture Imagery Program](#) (NAIP). NAIP is administered by the USDA Farm Service Agency to capture leaf-on, digital orthorectified aerial imagery over the continental United States, collected every 2-3 years during peak agricultural growing seasons. Imagery is captured on a state-by-state basis and spatial resolution and the date of latest acquisition may vary by location.

- **Advantages:** NAIP imagery is orthorectified and users can access compressed county mosaics or digital ortho quarter quads (DOQQs). The data is typically 1 m or higher spatial resolution with 4-band blue, green, red, and near-infrared bands. Some collections might only include the 3 visible (blue, green, and red) bands. Excellent resource for free high-quality recent historical data (2003-current).
- **Disadvantages:** NAIP imagery is captured on a rotating basis across the US and may not be available for the current calendar year or season required for easement monitoring.
- **Additional Considerations:** The NAIP public domain model might change to a for-cost license model, or potentially cover limited areas in the future. Currently NAIP imagery can be accessed through several sites including the [USGS Geospatial Data Gateway](#) and through the [USGS National Map Image service](#).

Unmanned Aerial Vehicles (UAVs): UAVs, commonly called drones, are becoming increasingly popular with conservation and other land management users. There are many different types of drones on the market, and varying quality cameras can be used to capture imagery. Several land trusts are using equipment they have purchased, while others hire a company or drone pilot to acquire imagery.

- **Advantages:** Drones are typically owned and operated by the user so users can control when and where to capture data. Image quality is dependent on the camera characteristics and the software used for processing. Technology is new and might appeal to landowners, which can help with public relations and relationship building.
- **Disadvantages:** Setup costs are considerable if the organization is purchasing equipment. Flying drones for commercial uses also requires an FAA Remote Pilot Certificate. There are flight restrictions at many locations (near airports, military bases, etc.), that may impact an organization's ability to capture imagery. Drone flights still require stewardship staff to be present on the ground, so cost savings to staff time might not be as significant as other methods.
- **Additional considerations:** The organizations interviewed for this study note that drones work best for hard to traverse locations that are smaller than 1000 acres, due to power supply and line-of-sight restrictions.

Satellite Imagery

Moderate-Resolution Satellite imagery: Moderate-resolution typically refers to satellites such as Landsat and Sentinel 2, which have spatial resolutions of 30-10 meters depending on the spectral band. These satellites are operated by the USGS and the European Space Agency respectively, and their data are made freely available to the public.

- **Advantages:** Both Landsat and Sentinel 2 offer freely available, very high quality orthorectified imagery with multiple spectral bands which is suitable for advanced image analysis such as change detection and vegetation health studies in addition to regular monitoring. Landsat has been in operation since 1972 so offers a dense historical record that covers the entire globe.

These systems also continuously collect data over land areas, so imagery is typically available, depending on cloud cover.

- **Disadvantages:** spatial resolution is not always high enough to detect some types of compliance events needed to monitor properties, dependent on easement terms.
- **Additional Considerations:** New techniques are being developed that allow users to automatically flag anomalous pixels from dense time series of imagery. While this approach is still in the research stage for assessing conservation easements it is promising as a tool suitable for regular, year-round monitoring to support on-the-ground efforts.

High-Resolution Satellite Imagery: High-resolution commonly refers to sensors that have 5 m or greater spatial resolution. There are various providers of these types of data including [Maxar](#), [Planet](#), and [Airbus](#), each with multiple satellites with varying spatial and spectral resolution.

- **Advantages:** Typically, high quality imagery with multiple spectral bands available, suitable for visual assessment in addition to more advanced change detection and vegetation analysis. Depending on the provider and funds available, data can be collected at a very high resolution (.3 m and .5 m available), which can provide the level of detail needed to detect many easement terms.
- **Disadvantages:** High-resolution image providers are private companies and the data is relatively expensive. Additionally, the imagery is licensed, often with restrictive use which limits the number of users of the data. Orthorectification is possible but typically requires an additional cost or effort to provide. Unlike Landsat and Sentinel, high-resolution satellites are not continuously collecting imagery. They operate on a “tasked” model, where imagery is recorded over areas that have been specifically requested (and paid for) or are commonly of interest to many users (i.e. major urban areas). One exception is Planet, which operates constellations of small satellites that image the entire globe daily.
- **Additional Considerations:** Similar to digital airborne and drone imagery, high-resolution satellite imagery often comes in very large data files, which require planning for data storage and hosting needs. Additionally, there are several different pricing structures and options for purchasing high-resolution satellite imagery:
 - *Tasked:* Tasked imagery is scheduled on demand and enables users to request imagery when and where it is needed, generally within an acquisition window. This is the most expensive and flexible option.
 - *Archived:* Archived imagery has already been collected, either as a routine collection by the image providers or as specifically tasked by a client. The high-resolution data providers sell this pre-existing archived imagery at a reduced cost. Because high-resolution satellites are not continuously collecting data, the availability of archived imagery for a particular area of interest is highly variable. Imagery might not be readily available for a particular calendar year.
 - *Subscription Service:* Several of the satellite imaging companies, including Maxar and Planet, offer subscription services to their imagery. Users can access archived imagery through a cloud-based web application for image viewing. Depending on the type of

subscription service, there may be an option for tasked imagery in certain regions. Under subscription services, images are available for viewing but not for downloading. This reduces the need for organizations to host and store the data on their own systems but also precludes the use of the data for automated image classification or other uses.

Additional Sources

Google Earth: Another popular free resource for high-resolution imagery is Google Earth. Google Earth is an online visualization platform that aggregates a variety of image sources over the globe.

- **Advantages:** For any area of interest, Google Earth aggregates available moderate and high-resolution data from both satellite and aerial sources. Historical imagery is also available in the platform which is valuable for tracking properties over time. Google Earth is easy to use and accessible to non-GIS users as well as geospatial analysts.
- **Disadvantages:** Imagery on Google Earth is typically not updated annually, and availability of coverage is highly dependent on the location of interest. Imagery is often published several months after acquisition, making it unusable for current year monitoring. Google also does not provide insight into an acquisition schedule, so it is not possible to plan for regular monitoring based on Google Earth imagery. Imagery may not be available for the time period and location of interest.
- **Additional Considerations:** Imagery from Google Earth is also not available for download, although it is possible to save screenshots for visual analysis and record keeping.

Study Results

Methodology and Process

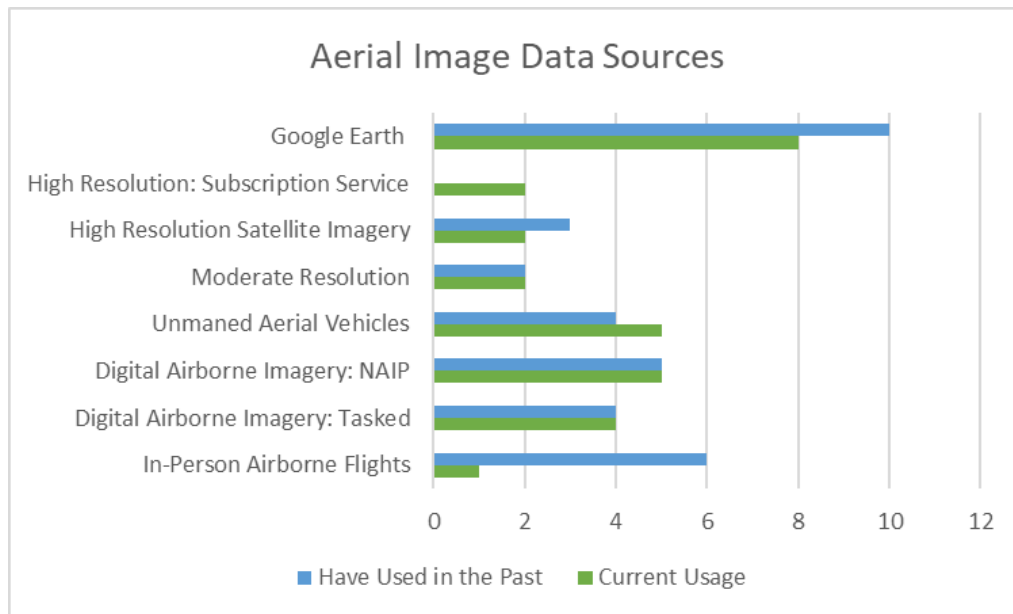
Land Trust Alliance (LTA) standards state that if organizations are using aerial monitoring for conservation easements, on-the-ground monitoring must occur at least once every five years. Organizations included in this study shared their protocols for both deciding what sites were suitable for remote monitoring, and how frequently remote monitoring and on-the-ground monitoring were employed.

The majority of organizations in this study utilize aerial or satellite imagery as a supplement to on-the-ground visits which they perform at each property annually. Many organizations interviewed used free data sources (including Google Earth and NAIP) as a general assessment on every site prior to going into the field. These organizations continue to visit every easement property on the ground every year. Airborne and satellite imagery serve to help guide the field visit and supplements the information gathered through on-the-ground monitoring. Organizations that use drone imagery as a source of compliance monitoring information still need to be physically on-site at the property and thus also visit annually although with reduced time.

Out of the 15 land trusts interviewed, four of the organizations have developed protocols that substitute remote sensing assessment for a portion of annual site visits. Some organizations have particular properties that benefit from remote monitoring, and other properties that are easy to visit on the

ground. Other organizations rotate between on-the-ground and remote monitoring for each suitable property. Typically, each property is assessed at the beginning of the year, with the assessment guiding the choice of which properties are suitable for remote monitoring during that cycle.

Organizations have employed a variety of different imaging technologies for their work and are moving away from traditional methods such as in-person airborne flights towards newer technology such as drones, as shown below:



Site Suitability for Remote Monitoring

There was general consensus among the interviewees that the types of sites that most benefit from aerial monitoring are those that are relatively large and difficult to access. For organizations that have mostly smaller properties that are easy for staff to drive to and visit on the ground, there may be little benefit to incorporating a remote monitoring protocol.

There are several key factors that organizations use to determine what sites are suitable for remote monitoring, including:

- Accessibility (travel to and from property, also accessibility on property)
 - Cost of monitoring on the ground
 - Size of property
 - Terrain/topography (steep, difficult to traverse on foot)
 - Sensitive or protected species
 - Distance to travel to property
- Landscape and landcover (some are easier to monitor from aerial view)
- Easement terms
- Recent or past history of violations

Sites that are difficult to access due to location, property size, topography, or other factors typically have a high cost in terms of staff time and resources for on-the-ground visits. In addition, property landcover and easement terms are key considerations. For example, some marsh and wetland properties may be extremely difficult to visit on the ground and violations can be readily seen from an aerial viewpoint. However, sites can also be under extensive tree canopy cover, which limits the ability to detect potential violations from remote monitoring, depending on the easement terms. Forested properties in the eastern United States are often imaged in the spring under leaf-off conditions. This allows for a high level of detection even in forested areas. Forests in the western United States and coniferous forests in general have continuous forest cover and thus violations may be more difficult to detect. However, many of these properties are primarily interested in forest thinning or cutting, which is readily detectable from moderate or high-resolution remote monitoring.

Each organization must assess the combination of factors listed above for each property to determine what methods will be best for their particular properties.

Image Analysis Methodology

The majority of organizations in our study currently rely on visual assessment of imagery to determine if potential easement violations have occurred. Stewardship staff typically review the most recent imagery in a GIS platform to compare the new image against historical data collected for that site. Although none of the land trusts in our study are currently using more advanced image analysis methods which exploit image spectral, textural, and contextual characteristics in-house, several groups are beginning to examine or explore automated or semi-automated methods of change detection, usually through partnerships with Universities or private consultants.

Image analysis methods being explored by land trusts include multiple years of high-resolution satellite and aerial imagery used for change detection to flag areas of potential concern. These flagged areas can then be identified and visited by stewardship staff on the ground. Other organizations are using freely available image sources including moderate-resolution imagery and NAIP to explore methods of automatically identifying potential areas of change through machine learning approaches. Conservation groups such as the Chesapeake Conservancy have developed methods using freely available high-resolution NAIP imagery to produce detailed land cover maps which can be used to help prioritize conservation efforts. Interviewees mentioned that they could see value in automated remote sensing analysis including vegetation mapping to support stewardship goals such as vegetation health monitoring in addition to change detection to flag potential areas of concern.

Reporting Process

The process of including imagery, imagery analysis, or results of visual assessment into annual easement reports varies among organizations. Typically, organizations that are using aerial monitoring to enhance yearly ground visits at every site will review imagery and check for areas that might be of potential concern. If there is nothing on the imagery to flag, normal reporting is done and no imagery is necessarily included in the reporting. In cases where there is a potential area of concern, the user might take a snapshot of the imagery and highlight the area of concern in GIS software to include within the report and to guide a field visit.

Organizations that supplant annual on-site visits with aerial monitoring have developed formal protocols for including this information into annual reports. For example, organizations may have a

standard spreadsheet that is filled out when visual assessment of high- resolution imagery is used for annual monitoring.

Lessons Learned

One of the goals of this study was to share best practices on implementing remote monitoring of conservations easements with a larger audience of land trusts who may be interested in getting started with this technology. Land trusts in this study agreed that the benefits of incorporating aerial monitoring outweigh the challenges. Key insights gained through these interviews include:

- There is no one single monitoring solution that is best for all land trusts for all properties, or in all years
- Remote monitoring and boots on the ground are **complementary** approaches
 - Remote monitoring does not eliminate the need for field visits but can supplant field monitoring in some years at some locations
 - Remote monitoring allows you to see violations you might miss on a ground visit
- As more and better imagery becomes available, potential cost saving is significant
- Less time spent on field monitoring visits means more time available for stewardship and conservation activities
- As remote monitoring becomes more widely used, it is critical to continue to develop and foster relationships with the landowners

Benefits

Increased efficiency in staff time and therefore reduced cost:

- Reduced time spent in travel and site visits allows more time to focus on stewardship and restoration work
- Improves ability to monitor difficult terrain: steep, marshy, hard to access locations
- Improved staff safety: stewardship staff could be traversing dangerous and isolated areas on the ground

Improvements to the quality of monitoring through the application of remote monitoring:

- Some types of easement violations are easier to detect from imagery
- Scalable and repeatable monitoring
- Ability to look at longer term trends with temporal/historical imagery

Even for organizations who visit each property on the ground every year, the ability to augment these visits by including an assessment of remotely sensed imagery to help guide time spent in the field results in a valuable cost savings through reduced staff time and in better monitoring outcomes. During these interviews there were several examples of violations that were missed during on- site visits which were subsequently captured through assessment of remotely sensed imagery.

Depending on the remote monitoring methodology employed, some users found that having new ways to communicate with landowners was an additional benefit. In particular, drone imagery still requires

on-site visits and can help to engage landowners. For example, the Bear Yuba Land Trust has found that some (although not all) landowners are eager to see drone technology in action. Bear Yuba's drone setup includes 3D goggles that users can wear to follow along with the drone flights, which has been enthusiastically received by several landowners.

Challenges

Challenges also exist when trying to incorporate digital imagery and analysis into an ongoing easement monitoring system. There was general agreement among the interviewees about the following difficulties in implementing various types of remote monitoring:

- Practical issues: some types of easement violations might not be detectable from aerial imagery, depending on image resolution, seasonality, and other factors.
 - Tree and cloud cover: can't see what is going on under the canopy with remote monitoring
- Difficulty in finding available imagery or in capturing cost effective imagery in the time period needed for your properties
- Less opportunity to build and maintain long term relationships with landowners if there is not an annual on ground visit
- Can be big investment of time and resources to get started (particularly with drones, also with other types of imagery)
 - Flying drone imagery requires an FAA Remote Pilot Certificate and users must understand and comply with local flight restrictions and regulations
- Difficult to define the return on investment
- Data size is often large, so data storage, processing, hosting, sharing, and management can be a challenge

Recommendations

Insights from land trusts we interviewed can help other organizations who are just starting or thinking about remote monitoring protocols. One helpful resource offered through the LTA is a webinar titled "Aerial Monitoring: Using Drones & Satellite Imagery", by Elias Grant and Kate Losey. Additionally, the following steps are recommended for organizations interested in incorporating remote monitoring into their annual process:

Get Started by Exploring Free, Local, and State Resources

- Many of the organizations we interviewed recommend that stewardship staff make it a practice to assess and review the freely available data as a regular part of preparation for field visits. Google Earth is a great resource for new users as it is free, easy to use, and often contains historical imagery in addition to recent data. NAIP is an excellent, no cost source of recent and historical aerial orthophotos. The image acquisition cycle for NAIP varies by state, and it may be helpful to know when the next updates will be within your region.
- Contacting other potential resources including state GIS agencies, Universities, and other conservation groups in your region may help to identify additional sources of data or ways to partner on image collections in your area. Some states and/or regions have extensive data

collections that land trusts may be able to make use of for easement monitoring. Universities may have aerial imagery or drone programs that would be willing partners for pilot projects.

- Although free data sources such as Google Earth and NAIP are not updated annually and thus are not suitable as a basis for regular annual monitoring programs, these resources can help to improve the quality and consistency of easement monitoring.

Assess Easement Properties, Terms, and Resources

- For organizations that are interested in exploring the benefits of remote monitoring, it is important to begin by assessing your easement properties, funding, staff resources, and support of your board. Are there properties that would benefit from additional image collection, either in place of or in addition to annual on-the-ground monitoring? As identified in our interviews, medium to large properties that are difficult to access and traverse with a history of few easement violations are good candidates for remote monitoring. An additional consideration is the organization's tolerance of the risk of not detecting a violation of terms.
- Consider the terms of each easement to determine what spatial resolution would be required to detect allowed and prohibited land uses using remote monitoring. Assess any additional requirements your organization may have for remote monitoring, such as a particular image acquisition time period.
- In making a cost/benefit assessment of remote monitoring, consider staff time and additional resources (gas, travel time, etc.) required to prepare for field visits, perform on-site monitoring, and report results for each property. How much staff time and resources would be required for remote monitoring of each property, and what might the cost savings be over several years?
- It is also critical to understand the expertise of your organization's stewardship staff, including their background and skills in GIS and remote sensing. For example, organizations with staff who already have drone pilot licenses are more likely to start working with drone imagery.
- If your organization is interested in working with drones, there are additional considerations including landowner preferences around drone flights, potential flight restrictions, and whether you would need to access any neighboring land for flights.

Consider What Type of Imagery would Best Meet Organization Needs

- Consider the advantages and disadvantages for different digital image sources which are briefly outlined in this report (p. 6-9). A key consideration is the image spatial resolution required to identify potential easement violations on each property.
- It may be useful to determine the availability of suitable archived imagery through satellite providers such as Maxar, Planet, or Airbus. Reviewing the imagery that is available on Google Earth can help to identify data coverage. Alternatively, [Apollo Mapping's Image Hunter](#) application allows users to search across several different high-resolution image providers for locations of interest. Areas with frequent coverage may allow for cost savings in the purchase of pre-existing archived imagery, rather than needing to task a satellite for coverage, which may be cost prohibitive for many land trusts.
- When considering the use of high-resolution satellite or airborne imagery, an organization should also consider how it will use the data and how it will be hosted, shared, and organized.

Does your organization need to purchase the data and retain the imagery in-house, or would a subscription service that allows staff to review imagery online meet your needs?

- One of the organizations we interviewed pointed out that having spatially accurate, high resolution imagery is very useful for baseline mapping, so it could be helpful to think about the added value this might provide with new properties.
- If interested in working with drones, consider hiring a drone pilot or consultant to test a few properties and review with your board before deciding to purchase your own equipment. In addition, drone imagery can be good for public relations. Several organizations we talked to have hired a professional company for drone footage to use in promotional material for their land trust.

Discussion and Conclusion

Land trusts in this study agreed that the benefits of incorporating aerial monitoring outweigh the challenges. The main benefit is increased efficiency in staff time and therefore reduced cost overall. In addition, land trusts also pointed out that there were significant improvements to the quality of monitoring through the application of aerial imagery and analysis. However, some types of violations require ground visits to assess, particularly those occurring under canopy cover or significantly below the pixel resolution.

A main finding from this study is that on-the-ground and remote monitoring are **complementary** approaches. Remote monitoring does not eliminate the need for field visits, but it does improve the quality of easement monitoring overall. Several groups mentioned that they had discovered easement violations through visual assessment of imagery that had been missed during on-the-ground visits. The increased efficiency in staff time found with remote monitoring systems made more time available for important stewardship and conservation activities. As more and better imagery becomes available and potentially more cost effective, the potential cost savings is significant for organizations on a budget.

Key challenges to implementing remote monitoring include the investment of time and resources needed to get started. High resolution imagery from either airborne flights or satellite providers can be expensive, particularly when a specific time window is required for imaging. The image subscription services offered by companies such as Maxar may be a more cost-efficient way to visually assess high resolution imagery, and also reduce the need for storing the data in-house. Startup costs for purchasing a drone and completing the necessary training can also be prohibitive. It is hoped that this document and the experiences of other organizations can help land trusts to begin to navigate some of the choices that need to be made to implement an efficient remote monitoring system.

An additional topic addressed in this study was staff capacity in working with aerial imagery. All of the land trusts interviewed have staff experienced with using spatial data and GIS, so staff capacity did not seem to be a barrier in implementing aerial imagery for visual assessments. However, staff in general did not have advance remote sensing skills which might be needed to develop in-house solutions for automated change detection, either from moderate resolution sensors such as Landsat and Sentinel, or for image analysis of high-resolution data. Partnerships with Universities or innovative for-profit companies such as Upstream Tech might be required to develop more sophisticated image analysis techniques for monitoring. Upstream Tech is developing a tool that uses free image sources including Landsat and Sentinel 2 to automatically identify outliers and flag potential areas of change. Advanced

image analysis can also benefit conservation organizations beyond easement stewardship, such as use of Lidar data to help understand vegetation structure and time series analysis that can help to track longer term trends in vegetation health or other indicators of ecological function.

As land trusts move towards substituting some on-site annual visits with remote imagery, it remains critical to build and maintain long term relationships with landowners. Several land trusts pointed out that annual visits are an important opportunity to connect with landowners that is lost with a remote system. It might be valuable to consider how to share this technology with landowners, whether that be a framed photograph of their property from a high-resolution image or following along on a drone flight with 3D goggles.

Having interviewed different land trusts around the country, it is clear that there is an increasing interest and awareness of the potential benefits in remote monitoring. As noted by stewardship staff who took part in this study, an ideal conservation monitoring system would include on-demand high resolution imagery in addition to regular on-the ground visits aided by a high-quality drone. One organization also added that having consistent and well-trained staff and having sufficient funding to support these staff is an important requirement for any ideal monitoring system. Industry leaders such as TNC may be able to take the lead in establishing advanced monitoring systems, paving the way for smaller organizations to take advantage of new technologies to improve land conservation efficiency.

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