RECLAMATION

*Managing Water in the West*

# Exploring the Feasibility and Versatility of Unmanned Aircraft Systems in Reclamation Mission Work

Research and Development Office
Science and Technology Program
Final Report ST-2016-0553-01

*Leica Aibot X6*

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# Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Within the Department of Interior, use of Unmanned Aircraft Systems (UAS) to support mission work is becoming more common, yet there is little understanding of how feasible UAS would be to support Reclamation work. This study explored how UAS could be used in four representative Reclamation work scenarios: bridge inspections, rockfall hazard identifications, orchard water use surveys, and aquatic surveys. The project team collected information by reviewing pertinent literature and interviewing subject matter experts. Information gathered indicates that while investing in a UAS program would not be expected to generate immediate cost savings in conducting work, the investment expenses could be offset by better quality data to support decision making, and reduced employee exposure to risks for when performing work tasks.

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**Peer Reviewer:** I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

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(Signature)

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# 1. Executive Summary

## Project Background

The goal of this S&T project was to explore the feasibility of utilizing Unmanned Aerial Systems (UAS) during the performance of Reclamation work within the Lower Colorado (LC) Region. Specifically, how UAS may improve the safety of working conditions for Reclamation employees, contractors and visitors; reduce costs; and improve the accuracy and quality of data products that lead to improved operations, maintenance and modernization of Reclamation infrastructure and resources.

## Study Process

The Lower Colorado Engineering Services Office (ESO) conducted an internal focus group with the project team to identify potential uses for UAS within current mission requirements. As a result, four mission scenarios were identified for analysis:

- Scenario 1: Aging Infrastructure - Bridge Inspections (Program Area: A50) -- within the Safety of Dams/Examination of Existing Systems mission area,
- Scenario 2: Inaccessible Features - Rock Fall Inspections (Program Area: A40/50) -- within the Examination of Existing Systems/Inaccessible Features mission area,
- Scenario 3: Water Use Accounting - Orchard Surveys (Program Area: A40) -- within the Water Operations mission area, and
- Scenario 4: Environmental Management - Habitat Surveys (Program Area: A30) -- within the Environmental Management/Restoration mission area.

The project team followed a three-stage process: primary-source data collection and development of a workflow diagram describing the current process; development of a workflow diagram detailing what the process flow could look like with UAS; development of qualitative and quantitative comparison (Benefit:Cost Analysis) was made between the two workflows to identify benefits to Reclamation from adopting UAS for mission work.

## Significant Findings and Recommendations

### UAS Mission Approvals

- Vehicle acquisition processes, UAS services acquisitions, and flight approvals are not well understood across Reclamation; this affects the degree of UAS use and flight approvals. Reclamation staff planning to either purchase UAS or utilize them for missions should plan long timeframes for UAS platform purchase and mission approvals.
- The 2015 Memo to the Reclamation Leadership Team (RLT) identifying the mission approval process doesn't require coordination with Reclamation's Security, Safety and Law Enforcement Office (SSLE) and Safety staff having jurisdiction for the facilities where the proposed mission will occur, which could result in key staff not being aware of

a proposed flight. Reclamation staff following the RLT Memo flight approval process should include SSLE and Safety staff with jurisdiction over the site where missions are proposed.

## Potential Missions and Analyses

- UAS can meet a need for low-altitude, small- to medium-area data collection (to provide access to areas which are inaccessible or unsafe to enter with personnel) utilizing high-resolution cameras and/or advanced sensors (to provide data not available either through manned means or from satellites).
- SMEs identified potential benefits to personnel safety through adopting UAS, as well as better quality data to support more advanced analysis tools. SMEs did not feel comfortable substituting UAS for people on missions. For the immediate future, UAS will be used alongside of, rather than instead of, people in field work, so UAS and crews will be additional costs to mission performance rather than reducing the costs of performing work. Managers interested in using UAS for mission work should expect to incur additional costs to incorporate UAS technology into mission work, offset by benefits to personnel safety and in the form of better quality data for analysis.
- Interviewees identified high resolution imagery as the key deliverable from UAS data collection. There was limited understanding of how UAS-collected data from advanced sensors and input into analytical tools could be used to support better decision-making. To realize the full utility of UAS-collected data, new software tools and/or training will be needed to allow enhanced analyses and support decision-making.

## Findings Specific to Mission Scenarios

Scenario 1: Aging Infrastructure - Bridge Inspections (Program Area: A50)

- In this scenario, UAS is considered useful mainly because of the generally small, concentrated mission areas, potential to improve personnel safety through reduced staff inspections via rope, and potential to utilize data collected from advanced sensors in improved data analysis tools.
- SMEs expressed that UAS could potentially replace rope team staff in gathering data about bridge conditions and defects. However, they had concerns that inspectors might make lower-quality decisions if they had to base them on UAS-gathered imagery rather than hands- and eyes-on observations.
- Special focus would be needed to ensure availability of a UAS configuration that could observe upward, underneath a bridge.

Scenario 2: Inaccessible Features - Rock Fall Inspections (Program Area: A40/50)

- In this scenario, UAS is considered useful because of the generally small mission areas, potential to improve personnel safety, and potential to utilize data collected from advanced sensors in improved data analysis tools.

- SMEs expressed that UAS could supplement inspection staff in gathering data about potential rockfall hazards.
- They felt that better data products could be gathered through using UAS, and that personnel safety could be positively impacted.

Scenario 3: Water Use Accounting - Orchard Surveys (Program Area: A40)

- SMEs felt UAS would be less useful in this scenario. Contributing factors include that orchards which are not accessible on one trip may be accessed during a later trip; large mission areas (which would require multiple flights and extensive land-owner notification); potentially extensive team coordination to optimize the use of UAS; and that satellite data is already used early in the data analysis process.
- SMEs expressed that UAS could supplement orchard survey crews during ground truthing trips, but might not be critical to more efficient or effective completion of the work.
- Benefits to using UAS would likely be offset by the additional logistical requirements of getting approval to use UAS, requirement to notify landowners whose property would be overflown during UAS flights, and the coordination required to optimize UAS use during ground truthing trips.

Scenario 4: Environmental Management - Habitat Surveys (Program Area: A30)

- In this scenario, UAS is considered useful because UAS can be a less intrusive means to capture data on fish populations in generally small mission areas.
- Using UAS might mean additional mission costs as using UAS would require field teams of at least two people. SMEs expressed that UAS could supplement aquatic survey crews during data gathering trips, and that UAS could potentially allow less invasive data collection due to their smaller size and quieter operations (compared to manned flights).
- SMEs also valued the potential increased flexibility of re-scheduling data collection flights in response to near-term weather condition changes.

**Benefit:Cost Analysis Benefits Summary Table.** The project team identified potential qualitative benefits in the areas of risk reduction; environmental, economic and social benefits; data products; and mission execution. Table 1 below is divided into two sections: Quantitative Benefits (in the form of avoided costs, or savings), and Qualitative Benefits. The project team conducted interviews with the mission SMEs to identify potential avoided costs or savings should UAS be used in missions. During those discussions, the project team asked SMEs to identify potential qualitative benefits. Grey cells in the table indicate no change between the current process and a process using UAS; green boxes indicate a perceived positive change, darker green boxes a greater perceived positive change, and orange boxes a perceived negative change.

Table 1. Benefit:Cost Analysis Benefits Summary

| Benefit-Cost Analysis Benefits Summary | | | | |
|---|---|---|---|---|
| **Quantitative Benefits Summary** | **Orchard** | **Aquatic** | **Bridges** | **Rockfall** |
| **Avoided Costs** | **Benefit** | **Benefit** | **Benefit** | **Benefit** |
| Staff time + overtime | $0 | $0 | $ 51,840 | $0 |
| Hazard pay | $0 | $0 | $ 3,240 | $0 |
| Lodging and M&IE costs | $0 | $0 | $ 1,238 | $0 |
| Fuel costs | $0 | $0 | $0 | $0 |
| Administrative costs | $0 | $0 | $0 | $0 |
| Equipment operations & maintenance | $0 | $0 | $0 | $0 |
| **Qualitative Benefits Summary** | **Orchard** | **Aquatic** | **Bridges** | **Rockfall** |
| **Risk Reduction** | **Benefit** | **Benefit** | **Benefit** | **Benefit** |
| Reduction in risk to employees | + | 0 | ++ | + |
| Reduction in risk of facility damage or failure | 0 | 0 | 0 | ++ |
| **Environmental, Economic, and Social Benefits** | | | | |
| Reduced carbon footprint (assuming electric UAS) | 0 | 0 | 0 | 0 |
| Efficient, effective, and transparent decisions | + | + | - | ++ |
| Facilitation of interagency relationships | 0 | + | 0 | + |
| **Data Products** | | | | |
| Collection of new data | + | + | + | ++ |
| Improved data quality | + | + | 0 | ++ |
| Improved data objectivity | + | 0 | 0 | ++ |
| Support of open and accessible data initiatives | 0 | 0 | 0 | 0 |
| **Mission Execution** | | | | |
| Mission through-put (beginning to end of mission duration) | 0 | 0 | -- | 0 |
| Difficulty to execute the overall process | + | 0 | -- | - |

## Recommendations

- **Guidance Exists to Support Program Development:** There appears to be sufficient guidance from both OAS and within Reclamation to support Reclamation offices interested in obtaining a UAS and/or conducting missions. In particular, there is extensive public information available about UAS platforms and applications; a range of potential Reclamation missions which could benefit from the addition of UAS; agency Aviation program staff and structure for program oversight; technical staff interested in learning to utilize UAS and data processing tools; and program managers interested in benefits which can be derived from using UAS in mission work. Reclamation offices wishing to invest the time and resources into a UAS program should be able to follow a fairly straight-forward path.
- **Program Management Models:** Reclamation should consider how to manage its UAS program(s) and communicate that information. Example management models include: (1) Each Directorate manages its own UAS Program (as in the way the Agency manages its Rope Teams); (2) Semi-Centralized Program Management -- two or three Regions house

UAS programs and offer services to Reclamation (as in the way Reclamation handles the Dive Teams); (3) Centralized management from a single office -- a single office maintains a program and offers services to Reclamation (as in the way Reclamation handles the CCTV program). Potential decision criteria to analyze how to manage the program(s) include the costs to invest in and maintain a UAS platform and sensors, costs to obtain and maintain staff certifications and expertise, and need and desired depth of agency expertise in this area.

- **Flight Approvals:** An appropriate person or group should solicit feedback on the Reclamation UAS mission approval process described in the RLT Memo to gather lessons learned from recent flights, and the updated information should be distributed to Reclamation staff.
- **Mission Expenses vs. Savings:** When adopting UAS, managers should plan to incur additional costs which are anticipated to be offset by qualitative benefits to personnel safety and in the form of higher-quality data to develop more advanced analysis tools than currently exist. As more experience with missions creates awareness of how savings could be generated, it is possible that more expenses could be offset by financial savings.
- **Inaccessible Features Inspections Missions:** Reclamation offices responsible for assessing and mitigating rockfall hazards should consider exploring how UAS could be included as a tool to improve personnel safety and decision making effectiveness. UAS could be used to reduce the time personnel spend conducting work on ropes, while creating a more extensive dataset to use in assessing hazards.
- **Facilities Inspections Missions:** Reclamation offices responsible for operating and maintaining dams and bridges should consider adopting UAS and using the systems on facilities inspection missions. Other possible uses include inspections of facilities such as roofs, transformers, or towers, potentially using infrared or thermal sensing. Higher-quality data obtained would be used to help offices identify maintenance and repair needs and avoid/minimize impacts to mission operations.
- **Survey and Geospatial Applications**: Reclamation offices collecting Survey and Geospatial data should consider adopting UAS to utilize the potential to quickly deliver high temporal and spatial resolution information. Real-time data collection for fast data acquisition, transmission, and processing could benefit the surveyors and geospatial programs by providing up to date information about mission locations and sites.
- **Data Analysis Tools:** UAS data collection can return large amounts and types of data, which need to be post-processed, managed and incorporated into tools to support analysis and decision-making. Reclamation offices planning to optimize UAS-collected data should budget for sufficient IT hardware, software, training and development time for staff to gain needed expertise. There will also need to be time invested in building awareness among program managers about what advanced tools are available and how they can be used to support analysis and decision-making.

- **Information Sharing on Using UAS in Reclamation:** Reclamation should re-convene the Reclamation UAS Community of Interest to share information about UAS best practices, missions, technology, and tools. The existing Reclamation UAS SharePoint site (https://teamsdrosp.bor.doi.net/tsc/uas/Pages/default.aspx) should be modified to include a message board or wiki option to facilitate information sharing among the Reclamation UAS community members.

# 2. Introduction

## Project Background

Unmanned aircraft systems (UAS) are a rapidly growing phenomenon. Not only is personal use exploding, but use in the commercial market is also quickly increasing. Goldman Sachs predicts that global UAS spending will reach $100 billion over the next five years (Poponak). An internet search reveals that many industries, specifically those that are agriculture or construction related, are utilizing UAS to lower costs and increase safety.

This project is funded through Reclamation's Science and Technology (S&T) Program as Project ID 0533, *Exploring the Feasibility and Versatility of Unmanned Aircraft Systems in Reclamation Mission Work.* The project goal is to explore the feasibility of utilizing UAS during the performance of Reclamation work within the Lower Colorado (LC) Region. Specifically, the project explored how UAS may improve the safety of working conditions for Reclamation employees, contractors and visitors; offer the potential to reduce costs; and improve the accuracy and quality of data products that lead to improved operations, maintenance and modernization of Reclamation infrastructure and resources.

The project team consisted of the following members shown in Table 2.

Table 2. Project Team Members

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# 3. Project Approach

The project team gathered information on UAS flight policy and vehicles approved for purchase and use within the Department of the Interior (DOI) and Reclamation; potential missions where UAS could be used; and the costs and benefits of using UAS within current mission requirements.

Once the mission areas were identified for analysis, the project team identified subject matter experts (SMEs) in each area and gathered data about the mission area and the potential applicability of UAS via interviews and review of relevant literature and policies. Information was captured in Tables, Process Diagrams, and a Benefit:Cost Analysis.

**Tables**. Responses provided during SME interviews were organized in tables to allow easy comparison of answers. The SME interview questions and responses can be found in each mission scenario.

**Process Diagrams.** Once the potential uses for UAS were identified in a mission area, the current workflow was mapped out along with a workflow that could be applied if UAS were used. Each mission was categorized into four general activity types: Pre-Mission Preparation, Data Collection, Post-Processing, Data Analysis/Decision-Making. The workflows were mapped side-by-side on the process diagrams for easy comparison, and characterized as "Current Process" and "With UAS Process." The "With UAS Process" was drafted assuming that a Reclamation-owned UAS will be used. The Process Diagrams can be found in Appendix 4.

**Benefit:Cost Analysis.** The project team included a Reclamation economist, who consulted with the team and SMEs to conduct a basic UAS Benefit:Cost Analysis. Data for the analysis was gathered through discussions with the SMEs and review of UAS literature. The framework built to analyze the benefits and costs can serve as a decision support framework for future studies. An in-depth Benefit:Cost Analysis table info can be found in Appendix 3.

# 4. Means for Using UAS in Reclamation

## Interior and Reclamation UAS Flight and Vehicle Policy

The project team researched methods of either obtaining a UAS for internal use or contracting for UAS services (including requesting flight services through the DOI Office of Aviation Services [OAS]). The project team identified four options and mapped each process to more easily understand potential advantages and disadvantages of each option. Mission approval process workflows can be found in Appendix 1.

The four methods explored for obtaining UAS services were:

1. Purchasing directed UAS services through a private-sector contractor on a per-mission basis.

2. Making an end-product purchase with specifications that would require use of a UAS (e.g., specifying data at a specific resolution and type rather than actually requesting use of a UAS).
3. Working with a cooperative agency (such as a university) to purchase either a UAS flight or end-product requiring UAS support.
4. Agency purchase of a UAS.

## Contracting for UAS Services

Factors associated with contracting for UAS services include:

- OAS has primacy for contracting, and there is the potential for long contracting lead times;
- Requestors will need to determine whether Reclamation will retain "operational control" of a mission;
- Requestors will need to navigate an evolving agency-specific flight approval process in addition to the existing FAA/OAS approval process.

The Federal Aviation Administration (FAA) considers UAS to be aircraft, with the DOI OAS responsible for the contracting of any UAS. The OAS suggests that organizations planning to contract for UAS services should allow 120 days lead time for a competitive bid and 160 days for a non-competitive bid. Within Reclamation, people wanting to secure UAS services would start by reaching out to their Regional Aviation Manager for more information on the appropriate process to follow; the process will also involve Reclamation's Safety, Security and Law Enforcement (SSLE) Office, and Reclamation's National Aviation Manager.

When planning to contract for UAS services, requestors need to determine whether they will retain "operational control" over the mission. (Per Operational Procedure Memo (OPM) 11, "operational control" with respect to a flight means the exercise of authority over initiating, conducting, or terminating a flight, as well as assuming responsibility for the airworthiness of the UAS). If the requestor maintains operational control of the flight, Reclamation will be required to supply a pilot-in-command (someone who has received DOI approved training as a remote pilot) for the mission, and liability for the mission will remain with Reclamation.

Without operational control, the contractor maintains liability but also needs to obtain a certificate of authorization from the FAA as well as any land-use permits necessary, including through Reclamation. In either case, Government agency notification must be written whereas non-governmental agencies are not required to be written; however, internal policy will dictate. It is estimated that the entire process would likely take between 180 and 210 days, depending on the contract.

One avenue for managing liability and oversight requirements is to transfer operational control to the UAS services contractor by writing a performance statement of work for an End-Product Purchase (see section below), specifying as the deliverable data of a type and resolution which

would require a UAS to gather the requested data, without specifically identifying a "UAS flight" as the contracted service.

## End-Product Purchase

An End-Product purchase is the simplest process for "using UAS." An end-product purchase is **NOT** a direct request for using UAS for anything. An end-product purchase would follow the agency contracting process, including purchasing services via credit card if the purchase is small enough. The purchase request would be for an **END PRODUCT;** it would only describe the desired quantity or quality of the service or deliverable. The purchase request would not specify that the end product is to be obtained via UAS (since OAS is responsible for contracting UAS), instead leaving the method of data collection at the discretion of the contractor.

Examples available of acceptable language for end-product contracts can be accessed in Appendix 1. When making an end-product purchase, if the contractor elects to use UAS, DOI personnel must not become involved in any way with ground operations and have no authority whatsoever regarding any UAS flight. The expected time to complete the process could range from a couple of weeks (if a credit card purchase) and several months if contracted.

## Securing UAS Services through a Cooperating Agency

Considerations for working with a cooperating agency to gather data via a UAS mission are similar to those for working through a contractor: potentially long lead times to develop an agreement (possibly up to 18 months); the need to determine who will have operational control of the mission; and an evolving internal approval processes for missions.

Reclamation is not required to work through the OAS when arranging UAS services through a cooperating agency, but would need to develop a cooperative agreement to cover the provision of services and other relevant factors, including data ownership and management, handling any sensitive data and identifying any restrictions on the data; all data must be handled in accordance with Reclamation Manual SLE 02-01 *Identifying and Safeguarding For Official Use Only (FOUO) Information*. Once the agreement is complete, the process does not have to be repeated with the same cooperating agency, so future missions would need only follow the internal approval process.

Under an active agreement, the individual pre-flight approval process is similar to that under the contracted option with respect to operational control, land-use permits, and landowners. However, the lead time for flights can be reduced because an agreement is in place and a new contract would not need to be developed. Depending on the circumstances, the potential time to complete the process (after agreement is in place) could be between 90 and 120 days.

## Reclamation Purchase of UAS

Similar to the Cooperative Agency process, if an agency wants to purchase its own UAS, there is a lengthy process that must be completed beforehand. In March of 2016, DOI released a memo titled *Guidance for prospective DOI's UAS Manager and Program Developers* (Startup

Guidance), which can be found in Appendix 2. The memo contains a process flow to be followed by any agency interested in purchasing a UAS. The flow encompasses the process from the earliest consideration of using UAS, through pilot training, purchase of the UAS, and steps immediately preceding and following a mission. The approval document produced is called an Operational Test and Evaluation Proposal (OT&E).

Once a UAS is in the possession of an agency, the steps to follow to conduct a mission include obtaining DOI and Reclamation approvals, obtaining permits, sending notifications, and executing the mission. Depending on the circumstances, the expected time to complete the mission process (after OT&E process is complete) could be between 90 and 120 days.

One key approval step involves notifying landowners whose land will be overflown that the flight is planned. If the UAS is taking off and landing on Reclamation land, no land-use permit is needed; however, if other agency / landowner lands are utilized, a land-use permit is required and would be obtained through the Lands Office of the area office having jurisdiction over the mission location.

To begin the process of acquiring a UAS, Reclamation program planners would consult the Startup Guidance, which contains a process flow for initiating a program and a template for an OTE package. Two directorates within Reclamation have completed OTE documentation -- the Pacific Northwest Region and the Technical Services Center. Those completed packages can be found in Appendix 2.

## Considerations When Selecting an Option for Obtaining UAS Services

When the four options are analyzed, it could be argued that one of the most important decisions will be whether to purchase the agency's own UAS, or use one that belongs to someone else. Although owning a UAS makes the actual missions easier to plan, there are some significant items to consider before making a purchase and creating an internal UAS program. First of all, and most obvious, are the up-front costs related to the initial purchase of the UAS. Current approved models range from between $3,000 and $30,000 each, not including sensors, cameras, and any other specialized equipment. In addition, a program must contain trained remote pilots, trained spotters, and trained supervisors. Each of these must become certified, and each must maintain the certifications in order to fly. Each UAS model also has its own training certification that must be obtained before a pilot can operate it. It is estimated that UAS-related activities will encompass up to 30% of an employee's time in order to maintain certification. Additional considerations include specialized modeling software, software licensing and training, and maintenance, all while the industry is experiencing rapid growth where UAS models could quickly become obsolete.

# 5. UAS Mission Approvals

Pursuing approval to fly a UAS mission in Reclamation is at least a two-phase, multi-step process, involving a DOI-defined process and an internal Reclamation process. Mission planners must comply with both DOI OAS requirements and Reclamation's requirements. The DOI approval workflow is depicted in the individual diagrams mapping the processes for securing UAS services; the Reclamation approval process workflow is depicted in a separate diagram. Both diagrams can be found in Appendix 1.

## DOI Approval for UAS Missions

The DOI-defined approval process is described in Operational Procedures Memorandum (OPM) - 11 DOI Use of Unmanned Aircraft Systems, dated January 1, 2016. DOI issued the memo prior to the Federal Aviation Administration's release of 14 CFR Part 107 - Small Unmanned Aircraft Regulations, and is being updated to reflect the new regulations.

The memo discusses multiple considerations that relate to using UAS within the DOI, including:

- defining DOI policy that UAS are considered aircraft and programmatically managed by OAS;
- identifying key roles and responsibilities regarding program management, compliance requirements, and protections;
- describing procedures and guidelines for acquiring UAS and securing approvals to conduct UAS missions, including identifying the forms and information required to obtain a UAS or UAS services (i.e., the Operational Test and Evaluation memo or OTE)

Among the requirements listed in the OPM-11 is for agencies to comply with privacy, civil rights and civil liberties protections. To support compliance with that requirement, the DOI OAS in January 2016 completed a Privacy Impact Assessment (PIA) for UAS operations within the DOI. This UAS PIA can be referenced when mission planners are completing Reclamation's mission approval request forms (see Appendix 1).

The DOI approval process steps vary depending on whether a mission is being flown with a DOI-owned vehicle or partner/vendor-owned vehicle, and depending on whether the government or partner/vendor has operational control of the mission. Process diagrams mapping the different approval workflows for each mission types can be found in Appendix 1.

## Reclamation Approval for UAS Missions

Reclamation issued a memorandum to the Reclamation Leadership Team on 3/26/15, titled Unmanned Aircraft Systems (see Appendix 1). The memo identified the following required documentation for UAS use on a task by task basis:

- Purpose and scope of UAS usage
- Information to be gathered
- Controls to be implemented to ensure privacy and protection of civil rights

- The plan for preserving information gathered as official records
- Approval by the Regional Aviation Manager
- Approval by the Regional Director where the work will be performed.

The following additional approvals are also be applicable when coordinating a mission request:

- Regional Safety Manager
- Regional Security Manager
- Facility Manager where the work will be performed

Reclamation personnel planning missions have completed paperwork providing the information and approvals listed above. UAS missions are known to have occurred in the PN and UC Regions. The PN Region uses its own UAS and pilot; the UC Region missions were conducted with services provided by cooperating agencies. Approval documents used for a 2016 UC Region mission can be found in Appendix 1.

# 6. Potential Missions and Analyses

## Potential Reclamation Applications for UAS Services

In July 2015, the DOI produced a strategy to integrate UAS into DOI operations (Strategy). The Strategy's introduction stated: "DOI missions can be hazardous to personnel, require persistent presence, and often need to be conducted without disturbing native species or visitors to our lands. Development of the UAS program within DOI will support in the accomplishment of our mission through better ***Science***, greater ***Safety***, and increased ***Savings***.[sic]" The study identified a diverse set of potential uses for UAS within DOI, with the top six being wildlife-related services, fire-related services, miscellaneous services, vegetation-related services, general imagery, and law enforcement (*Bathrick*).

Within Reclamation, Douglas Clark of the Geographic Applications and Analysis Group at the Denver TSC polled the Reclamation UAS Community of Interest on potential UAS missions and locations. He produced a summary of the poll which identified the top five potential applications as remote sensing, mapping, surveying; facilities-related services; environmental services; security services; and collecting data in difficult to access areas *(Clark)*. The summary can be found in Appendix 2.

To select mission areas to explore in this project, the LC ESO conducted an internal focus group with the project team to identify potential uses for UAS within current mission requirements. As a result, four mission scenarios were identified for analysis:

- Scenario 1: Aging Infrastructure - Bridge Inspections (Program Area: A50) -- within the Safety of Dams/Examination of Existing Systems mission area,
- Scenario 2: Inaccessible Features - Rock Fall Inspections (Program Area: A40/50) -- within the Examination of Existing Systems/Inaccessible Features mission area,
- Scenario 3: Water Use Accounting - Orchard Surveys (Program Area: A40) -- within the Water Operations mission area, and

- Scenario 4: Environmental Management - Habitat Surveys (Program Area: A30) -- within the Environmental Management/Restoration mission area.

## Scenario 1: Aging Infrastructure - Bridge Inspections (Program Area: A50 - Facilities Maintenance and Rehabilitation)

There are 110 Type-1 bridges in the LC Region. Each of these bridges is required by Federal Highways Administration (FHWA) regulations to be inspected at least once every two years and the report submitted to FHWA.

A vast majority of the 110 bridges are very small and span narrow canals or washes. Interviews with bridge SMEs indicated that these small bridges don't appear to merit the use of UAS and that any additional benefit gained from high-quality imagery or 3D modeling data that could be obtained through the use of UAS would be marginal at best. In addition, a majority of those bridges are too low to the ground to safely fly beneath and those that aren't only require two to three person-hours to safely inspect on foot.

However, there are a handful of bridges (8 total, which are inspected bi-annually, leading to inspections of 4 bridges per year) that do require rope teams and/or dive teams to support inspections. These bridges are the most likely candidates to find the use of UAS beneficial, both in terms of cost and safety benefits.

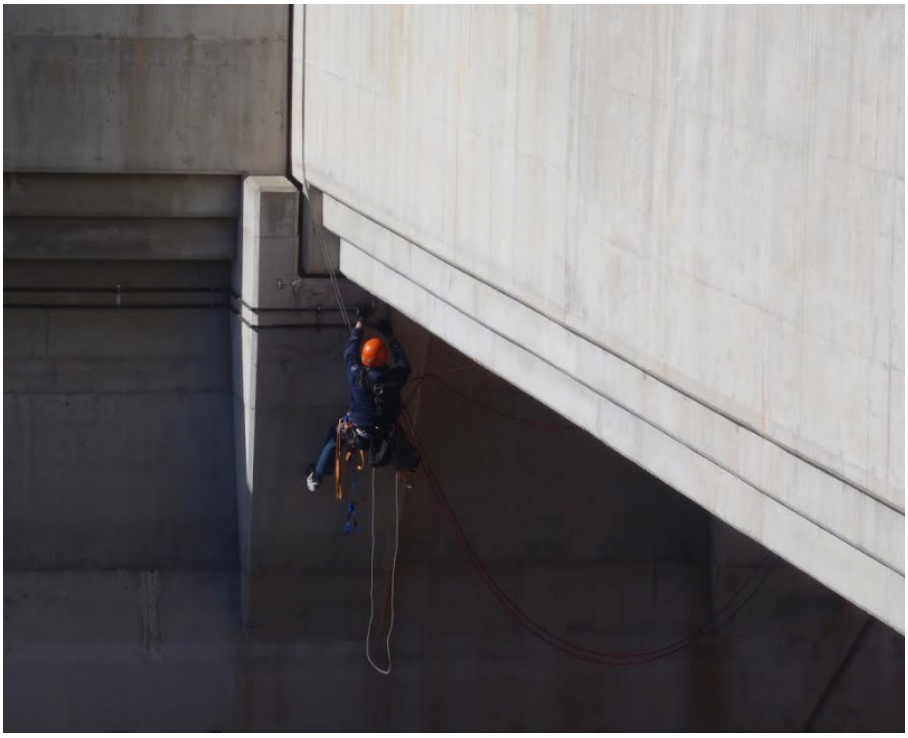


*Photo 02: Hoover intake bridge inspection.*

*Photo 03: California wasteway bridge In Yuma.*

## Tabular Info from SME Interviews

The compilation of the workflows was followed by additional discussions with the SMEs. During those discussions, additional mission-related information was gathered while discussing the differences between the two workflows. The information was sorted and placed into a tabular format for easy comparison.

| | **Aging Infrastructure - Bridge Inspections - W/O UAS** | **Aging Infrastructure - Bridge Inspections with UAS** |
|---|---|---|
| | **General** | |
| Program Area | Facility Maintenance and Rehabilitation | Facility Maintenance and Rehabilitation |
| Mission purpose | Gather data related to the condition of aging infrastructure; specifically, bridges. | Gather data related to the condition of aging infrastructure; specifically, bridges. |
| Authority/ Requirement | To comply with Federal Highway Administration (FHWA) requirements. | To comply with Federal Highway Administration (FHWA) requirements. |
| Number of Sites | LC -110 Type-1, 8 using rope teams. Bridges inspected include: 5 at Parker Dam, 1 at Hoover Spillway, 1 at Davis Dam, and 1 or 2 unidentified bridges that are inspected periodically. | LC - 100 Type-1, 8 with UAS |
| Shortest possible duration from planning until data is obtained | 3 days. | Unknown, estimated 30 days based on mission approvals. Once the UAS is procured, the flight approval process should be fairly straight-forward. |

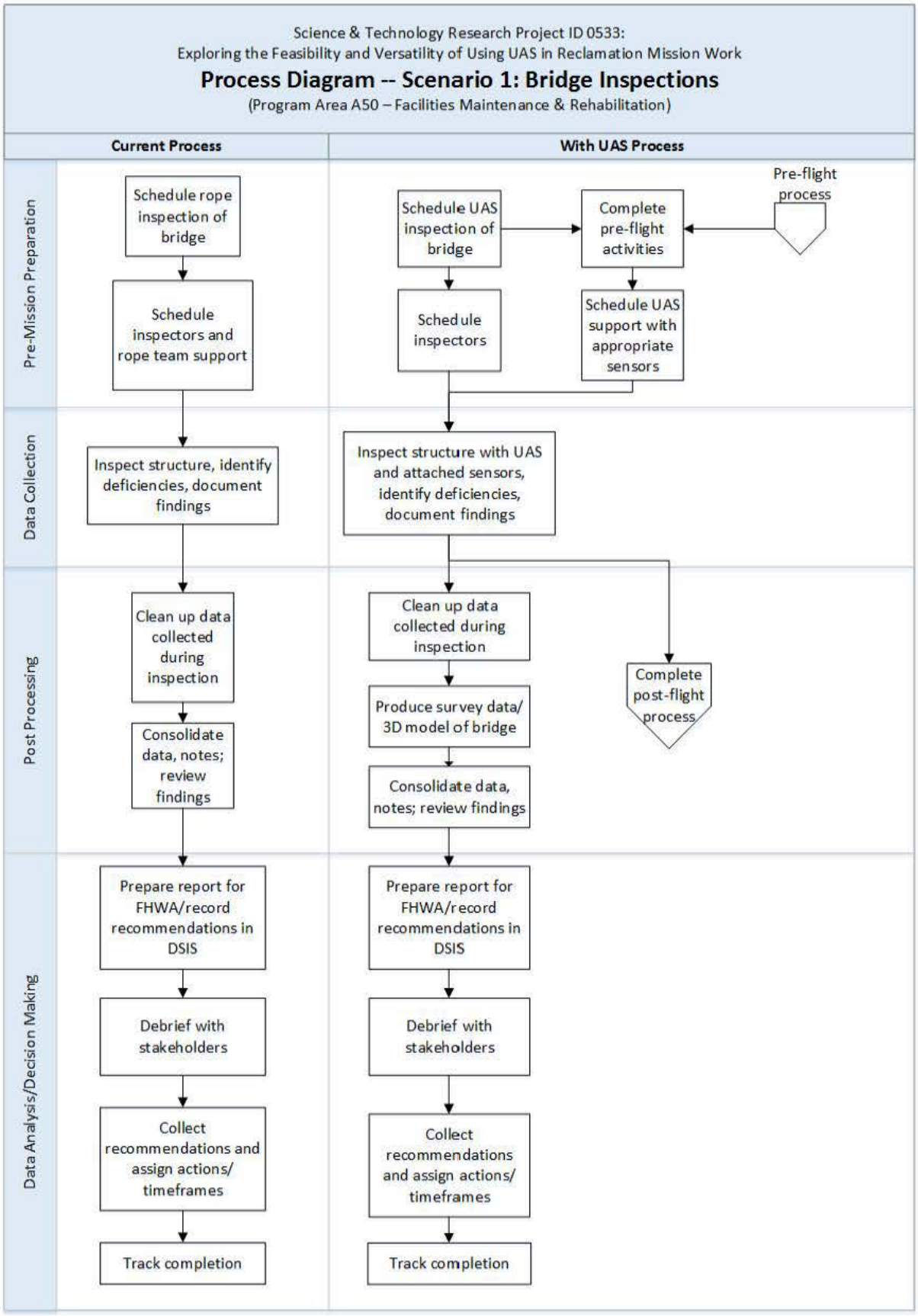
| Data | | |
|---|---|---|
| Data Collected | Observed deficiencies or deterioration such as: spalling (location, extent); cracks (depth/width of cracks); presence of scour on underside of bridge (measurements, location/depth); sediment build-up under the bridge; materials in the water; presence of exposed rebar (location); washouts beneath dry wash/bridges. | Same data as without UAS, with the option of collecting 3D imaging as well as any other data available using new sensor technology. |
| How Data is Collected | By field crew physically on location, suspended above the ground by secured ropes (i.e., rope team), or by physical examination under water (i.e., dive team). Photos are taken with a digital camera or cell phone. | By UAS utilizing high-definition cameras to take photo and video. Specialized sensors for beyond-visual range imagery, 3D imaging. |
| Data Format | Hand-written notes and photographs (JPGs). | Hand-written notes, jpg, mp4, dxf, 3ds, etc. |
| Data Quality | Low to high resolution photos. | High-definition photo and video, 3D digital quality, point clouds, multi/hyperspectral imagery. |
| Frequency of Collection | Type-1 bridges are inspected every 2 years unless condition assessment recommends more frequent. So, while the LC Region inspects 8 bridges, they are inspected bi-annually, equating to inspecting 4 bridges annually. | Type-1 bridges are inspected every 2 years unless condition assessment recommends more frequent. So, while the LC Region inspects 8 bridges, they are inspected bi-annually, equating to inspecting 4 bridges annually. |
| How Data is Processed | Notes are read, photos are reviewed. | Photos and video reviewed on-site and/or downloaded later. 3D imaging or other sensor-collected data exported to specialized modeling/analysis software. |
| Parameters Measured | Defect location, extent, depth, width. | Defect location, extent, depth, width. |
| How the Data is Used to Meet Mission Requirements | Through the use of inspection reports, inspections supply data about the presence of deficiencies that need to be repaired. Reclamation uses the data from inspections to make decisions about what actions are needed to maintain structures in safe and reliable working order. | Through the use of inspection reports, inspections supply data about the presence of deficiencies that need to be repaired. Reclamation uses the data from inspections to make decisions about what actions are needed to maintain structures in safe and reliable working order. |
| **Crew** | | |
| Number of Crew Members | Typically 2 inspectors along with a 3 to 4 person rope team. | 2 inspectors along with a 2-person UAS crew. |
| Qualifications | Pass a FHWA Certified Training course. Society of Professional Rope Access Technicians (SPRAT) certification. | Pass a FHWA certified training course, with the UAS crew possessing a remote pilot certification, spotter training, and UAS specific training. |
| Equipment | Rope and anchoring equipment, dive team equipment, camera. | UAS equipment including the vehicle, control system, launching system, and sensors. Specialized data analysis software and IT hardware. |
| Vehicles required to accommodate crew and equipment | SUV. | SUV, crew-cab pickup truck, or two vehicles. |

| | | |
|---|---|---|
| Interaction with outside entities | Irrigation Districts, Border Patrol, Cities. | Irrigation Districts, Border Patrol, Cities. |
| **Safety** | | |
| Safety for Contractors | N/A | N/A |
| Safety for Employees | Risk of falling, tripping from on-foot inspections and vehicular accident during travel to/from inspection site. Traffic offers the risk of getting injured by vehicle. Rope-related and dive-related hazards including injuries up to death. | Reduced risk of injury by falling, tripping, or vehicular accident. Slight risk of injury by UAS. |
| Safety for Visitors/General Public | Bridge inspections pose no risk to the public. | UAS cannot be flown over persons not associated with the mission; however, there is a slight risk to spectators if UAS crashes. |

## Process Diagrams for Current Workflows and "With UAS" Workflows

To provide insight to how using UAS would impact the mission planning and execution process, the current survey workflow was mapped out along with a workflow that could be relevant if UAS were utilized. The workflows were placed side-by-side for easy comparison. The "With UAS Process" was drafted with the assumption that a Reclamation-owned UAS will be utilized.

A PDF of the process diagram below can be found in Appendix 3.


Science & Technology Research Project ID 0533:
Exploring the Feasibility and Versatility of Using UAS in Reclamation Mission Work
Process Diagram -- Scenario 1: Bridge Inspections
(Program Area A50 – Facilities Maintenance & Rehabilitation)
Current Process
With UAS Process
Pre-Mission Preparation
Data Collection
Post Processing
Data Analysis/Decision Making
Schedule rope inspection of bridge
Schedule inspectors and rope team support
Inspect structure, identify deficiencies, document findings
Clean up data collected during inspection
Consolidate data, notes; review findings
Prepare report for FHWA/record recommendations in DSIS
Debrief with stakeholders
Collect recommendations and assign actions/ timeframes
Track completion
Pre-flight process
Schedule UAS inspection of bridge
Complete pre-flight activities
Schedule inspectors
Schedule UAS support with appropriate sensors
Inspect structure with UAS and attached sensors, identify deficiencies, document findings
Clean up data collected during inspection
Produce survey data/ 3D model of bridge
Consolidate data, notes; review findings
Complete post-flight process
Prepare report for FHWA/record recommendations in DSIS
Debrief with stakeholders
Collect recommendations and assign actions/ timeframes
Track completion

Review of the mission-related information identified opportunities and barriers to using UAS for bridge inspections. Opportunities identified included:

- Ability to inspect the bridge without having to send a rope team over the side of the bridge, eliminating the risk of falling due to a rope or anchor-related failure.
- Ability to collect a greater amount and/or quality of data, including ability to create an effective 3D model of a critical bridge. A 3D model could potentially have high value; however, decision-making based on a 3D model is currently being tested by various public entities. If the model could capture defects at a high level of detail, the analytical information available could be better than what can be gathered with the naked eye.
- Slightly reduced crew necessary to complete the inspection is also an advantage.

Barriers identified included:

- Lengthy and unclear UAS mission approval process. The current process needed to get approval to utilize a UAS takes a long time; within Reclamation, the process is evolving and not well-understood. This increases the overall mission timeframe and can create planning uncertainties. While the process is expected to become less time consuming over time as more people gain experience and the process becomes standardized, it currently represents a barrier to wider UAS use within Reclamation.
- Added process steps, resource requirements and staff capabilities to manage and manipulate the data into analytical tools. Managing high-resolution data requires additional, high-capacity hardware, advanced software, and transforming it into usable decision-support tools requires advanced technical user skills.
- Limited understanding of the capabilities offered by advanced sensors and analytical software and whether/how those could be leveraged into improved decision-support tools. SMEs stated that their desired data products were high-resolution video or imagery, and were concerned that UAS-collected data might be less trustworthy than data collected using current methods. It was not well understood what type of additional data could be provided by advanced sensors and software, or how that data could be used to support decision-making.

### Scenario 1 Benefit:Cost Analysis

Findings from the BCA included:

- Expenses of including UAS on bridge inspection missions identified as potential candidates range consist of an initial estimated investment of $74K and annual estimated expenses between $32K and $48K. Considering the monetized benefits identified by SMEs, the net present value of using UAS for bridge inspections over a 5-year period was estimated to be about $28K at a discount rate of 3.125%, and about $18K at a discount rate of 7%.
- The SMEs' qualitative assessment of using UAS to support bridge inspections indicated that they felt that using UAS could positively impact the safety of inspections, while

negatively impacting the overall planning and timeframes required to complete inspections, and possibly negatively impacting the quality of decisions made.

Note: The individual missions each identified costs for the UAS airframe, sensors, accessories, and specialized computer equipment and software, and this approach increased the costs identified for each mission type. In reality, were an airframe and accompanying accessories purchased for one type of mission, that equipment would be used for other missions, which would reduce the overall cost of the equipment. Those leveraged benefits are not identified in the BCA.

Data relating to these analyses can be found in Appendix 4.

## Scenario 2: Inaccessible Features - Rock Fall Inspections (Program Area: A40/50 - Facility Operations/Facility Maintenance & Rehabilitation)

Many Reclamation-owned facilities are located within or in close proximity of mountainous areas containing steep slopes and rocky soils. For example, the Hoover Dam facility is located directly between the El Dorado Mountains to the west and the Black Mountains of Arizona to the east. Part of Reclamation's Facility Operations, Maintenance and Rehabilitation missions entails conducting rockfall surveys to identify potential locations where rockfall could occur and mitigate those conditions. Mitigating rockfall potential at Reclamation facilities also addresses potential safety risks to the many employees and visitors who frequently pass directly below the cliff faces.

Rockfall surveys are conducted by Reclamation employees who descend slopes and cliff faces on ropes to locations previously identified by a geologist. The focus of a survey is to inspect and document areas where known defects exist and to identify any new areas of concern. When defects are identified, measurements are taken, photos are taken, and any existing debris is dealt with. The data is then brought back to the geologist for review and identification of any defects that require mitigation (usually done through contract services).

*Photo 04: Rockfall survey nearby the Arizona employee parking structure at the Hoover Dam.*

UAS could be utilized in various ways during rockfall surveys, depending on the situation. Initially, UAS could be utilized to inspect potential rockfall locations that are inaccessible to personnel due to extreme geologic barriers. The UAS could be flown to an inaccessible location and either take pictures and video of the location, or utilize sensor technology to gather non-visual data or develop a 3D model of the area.

In areas that are accessible to personnel, a UAS could be used to supplement manual data collection with photos and video taken from a distance. When photos are taken up close by the surveyor, it is often difficult to put the defect into perspective because the photo can only be taken at a maximum distance of arm's length. A UAS could fly further from the defect and observe the surrounding geologic characteristics at the same time. Eventually, as sensor technologies improve and comfort with using the technologies progresses, it is possible that the number of rockfall inspections requiring rope teams could decrease through the use of advanced imagery, 3D modeling software and resulting analytical and decision-support tools.

### Tabular Info from SME Interviews

The compilation of the workflows was followed by additional discussions with the SMEs. During those discussions, additional mission-related information was gathered while discussing the differences between the two workflows. The information was sorted and placed into a tabular format for easy comparison.

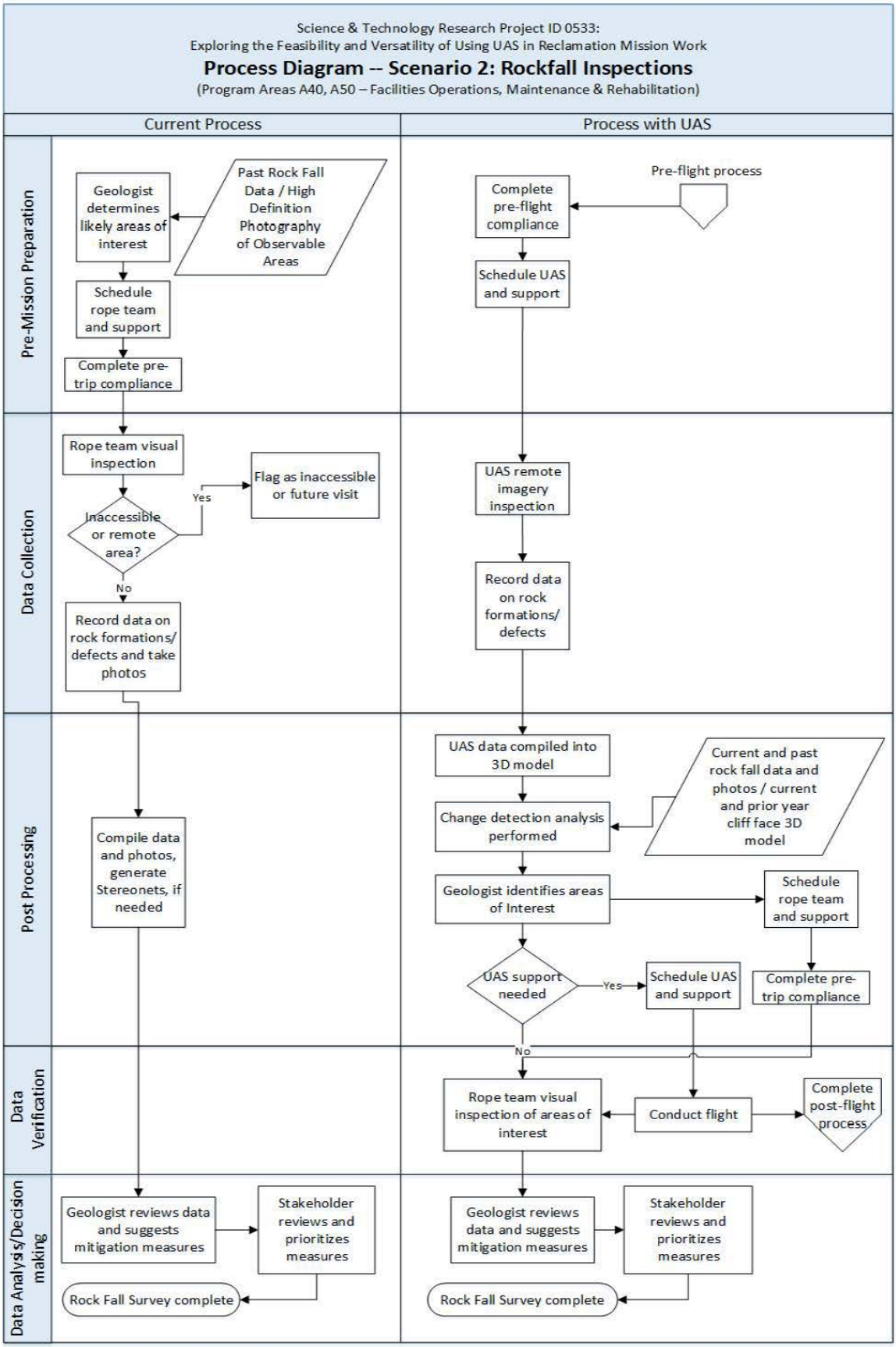
| | Inaccessible Features - Rockfall Inspections W/O UAS | Inaccessible Features - Rockfall Inspections with UAS |
|---|---|---|
| **General** | | |
| Program Area | Facility Operations, Maintenance and Rehabilitation | Facility Operations, Maintenance and Rehabilitation |
| Mission purpose | Decrease the risk of rockfall which in turn improves system reliability and increases public safety. | Decrease the risk of rockfall which in turn improves system reliability and increases public safety. |
| Number of sites | Hoover Dam area and 6 substations | Hoover Dam, 6 substations. In addition, the use of UAS may make the surveying of previously inaccessible sites possible. |
| Shortest possible duration from planning until data is obtained | Approximately 30 days | Unknown, estimated 30 days to 6 months based on mission approvals for UAS flights at national critical infrastructure facilities. Once the UAS is procured, the flight approval process may be fairly straightforward. |
| **Data** | | |
| Data Collected | Joint orientations:<br>- Strike - Direction of the line that is formed by the intersection of the place of the rock bed with the horizontal surface<br>- Dip - Direction of the steepest angle formed between the plane of the rock bed and the horizontal surface<br>Physical descriptions of the features (roughness, continuity, spacing), and the location of the feature on the slope<br>Areas where debris has accumulated on ledges or behind barriers. | Same data is collected with the added capability of using sensors to create 3D models or advanced analytical tools using specialized sensors and software. |
| How Data is Collected | By hand or, if the slope can be photographed (within certain constraints) from an accessible vantage point, software is available which can map the slope and calculate joint orientations. | By UAS to collect digital information (photographs, GPS info, other sensor data). The UAS would be flown to collect the initial data. After processing the data, potential trouble spots would be identified and rope teams would be deployed to inspect / mitigate the areas that needed immediate action. Contractors are hired to do the bolting, etc. |
| Data Format | Hand-written notes, jpg, mp4. | Hand-written notes, jpg, mp4, dxf, 3ds. Other modeling software formats. |
| Data Quality | Photos, but sometimes it's difficult to get photos capturing appropriate perspective and surrounding detail. | 3D, high resolution photos and/or point cloud data taken from a further distance. |
| Frequency of Collection | At Hoover, each site is inspected annually except power houses inspected every 5 years. | At Hoover, each site is inspected annually except power houses inspected every 5 years. |

| | | |
|---|---|---|
| | | Areas that were previously inaccessible may be done more or less frequently. |
| How Data is Processed | Hand-collected data is manually recorded, then entered into digital files which are used to build a diagram that shows three-dimensional data on a two-dimensional plane (called a stereonet). | Used with existing photogrammetry, data modeling or analysis software to map features and calculate joint orientations, possible locations of shifting rock. |
| Parameters Measured | Stability, required mitigation activities. | Stability, required mitigation activities. |
| How the Data is Used to Meet Mission Requirements | When potential rockfall locations are identified and mitigated, ideally the potential for rockfall is reduced or eliminated. | When potential rockfall locations are identified and mitigated, ideally the potential for rockfall is reduced or eliminated. |
| **Crew** | | |
| Number of Crew Members | 9 - 10 | 11 - 12 |
| Qualifications | Geologist, Society of Professional Rope Access Technicians (SPRAT) certification. | Geologist, SPRAT certification, UAS Pilot and spotter. |
| Equipment | Ropes, anchoring equipment. | Ropes, anchoring equipment, UAS and equipment. |
| Vehicles required to accommodate crew and equipment | No special vehicle requirement. | An additional vehicle large enough to carry the UAS and its equipment. |
| **Safety** | | |
| Safety for Contractors | N/A | N/A |
| Safety for Employees | Inspectors work connected to rope harnesses on sloping or vertical rock faces which exposes them to risk of injury from falling or jagged surfaces. | Ideally, fewer rope climbs would be necessary; or, the time connected to a rope would be reduced which decreases the likelihood of injury. Slight risk of injury while using the UAS. |
| Safety for Visitors / General Public | N/A | N/A |

## Process Diagrams for Current Workflows and “With UAS” Workflows

To provide insight to how using UAS would impact the mission planning and execution process, the current survey workflow was mapped out along with a workflow that could be relevant if UAS were utilized. The workflows were placed side-by-side for easy comparison. The “With UAS Process” was drafted with the assumption that a Reclamation-owned UAS will be utilized.

A PDF of the process diagram below can be found in Appendix 3.


Science & Technology Research Project ID 0533:
Exploring the Feasibility and Versatility of Using UAS in Reclamation Mission Work
Process Diagram -- Scenario 2: Rockfall Inspections
(Program Areas A40, A50 – Facilities Operations, Maintenance & Rehabilitation)
Current Process
Process with UAS
Pre-Mission Preparation
Geologist determines likely areas of interest
Past Rock Fall Data / High Definition Photography of Observable Areas
Schedule rope team and support
Complete pre-trip compliance
Pre-flight process
Complete pre-flight compliance
Schedule UAS and support
Data Collection
Rope team visual inspection
Inaccessible or remote area?
Yes
Flag as inaccessible or future visit
No
Record data on rock formations/ defects and take photos
UAS remote imagery inspection
Record data on rock formations/ defects
Post Processing
Compile data and photos, generate Stereonets, if needed
UAS data compiled into 3D model
Change detection analysis performed
Current and past rock fall data and photos / current and prior year cliff face 3D model
Geologist identifies areas of Interest
Schedule rope team and support
UAS support needed
Yes
Schedule UAS and support
Complete pre-trip compliance
No
Data Verification
Rope team visual inspection of areas of interest
Conduct flight
Complete post-flight process
Data Analysis/Decision making
Geologist reviews data and suggests mitigation measures
Stakeholder reviews and prioritizes measures
Rock Fall Survey complete
Geologist reviews data and suggests mitigation measures
Stakeholder reviews and prioritizes measures
Rock Fall Survey complete

Review of the mission-related information identified opportunities and barriers to using UAS for rockfall inspections. Opportunities identified included:

- Ability to gather initial information on rock faces without having to send a rope team, and ability to identify areas of further investigation using UAS-collected imagery. This reduces the amount of time people are on ropes, reducing risks of falling due to a rope or anchor-related failure.
- Ability to collect a greater amount and/or quality of data, including ability to create a 3D model or other analytical product for a critical rock face. If advanced data tools could capture defects at a high level of detail, the analytical information available could be better than what can be gathered with the naked eye.

Barriers identified included:

- Similar barriers as those identified through discussions with bridge inspection SMEs. See that section for a description of the barriers.

### Scenario 2 Benefit:Cost Analysis

Findings included:

- People were unwilling to replace staff with UAS; SMEs viewed the tools as additive, supplementing people rather than replacing people. The existing data collection process would occur as it does presently, with the addition of the pilot and spotter and their equipment to the team. The estimated expenses of including UAS on rockfall inspection missions identified as potential candidates consist of an initial investment of $76K and annual costs of between $23K and $38K. Without monetizing any qualitative benefits, the net present value of using UAS for rockfall inspections over a 5 year period was an estimated -$194k at a discount rate of 3.125%, and -$182k at a discount rate of 7%.
- The SMEs' qualitative assessment of using UAS to support rockfall surveys indicated that they felt that using UAS could positively impact the survey process in the area of employee/contractor/visitor safety; agency operations; data quality/accuracy, and interagency relationships. Drawbacks were identified in the area of executing the overall process based on additional complexity from mission planning and acquiring approvals.

Note: The individual missions each identified costs for the UAS airframe, sensors, accessories, and specialized computer equipment and software, and this approach increased the costs identified for each mission type. In reality, were an airframe and accompanying accessories purchased for one type of mission, that equipment would be used for other missions, which would reduce the overall cost of the equipment. Those leveraged benefits are not identified in the BCA.

Data relating to these analyses can be found in Appendix 4.

## Scenario 3: Water Use Accounting - Orchard Surveys (Program Area: A40 - Facility Operations)

Reclamation has various responsibilities under Article V of the Consolidated Decree of the United States Supreme Court in Arizona v. California, 547 U.S. 150 (2006), including accounting for and reporting on water use in the lower Colorado River Basin. One type of agricultural water use is orchard irrigation, typically done using flood irrigation. There are often large acreages of orchards moving in and out of production, which impacts water use on the system.

To keep track of orchard activity and maintain accurate reporting, the current process for estimating water use by an orchard involves obtaining LandSAT data through an agreement with USGS to compare the data to identify areas that might be orchards and have not previously been identified. Data from the analysis of current-year imagery is compared to historical data to flag fields to be visually inspected during ground verification operations, during which staff physically travel to orchards to visually inspect and record their findings. Data collected typically includes presence, status, and maturity of the orchard. This data is then used to estimate evapotranspiration by the orchard.

Due to known crop cycles, orchard surveys are completed at the same time as crop verifications which occur four times per year. Gathering and verifying information about orchards can be challenging because (1) new orchards can be difficult to identify using currently available imagery, and (2) locked gates sometimes prevent full access to orchards resulting in the orchard being marked for revisit during the next crop cycle. Although current methods usually obtain all of the information needed annually, UAS was considered to provide possible service in addressing the two challenges identified above.

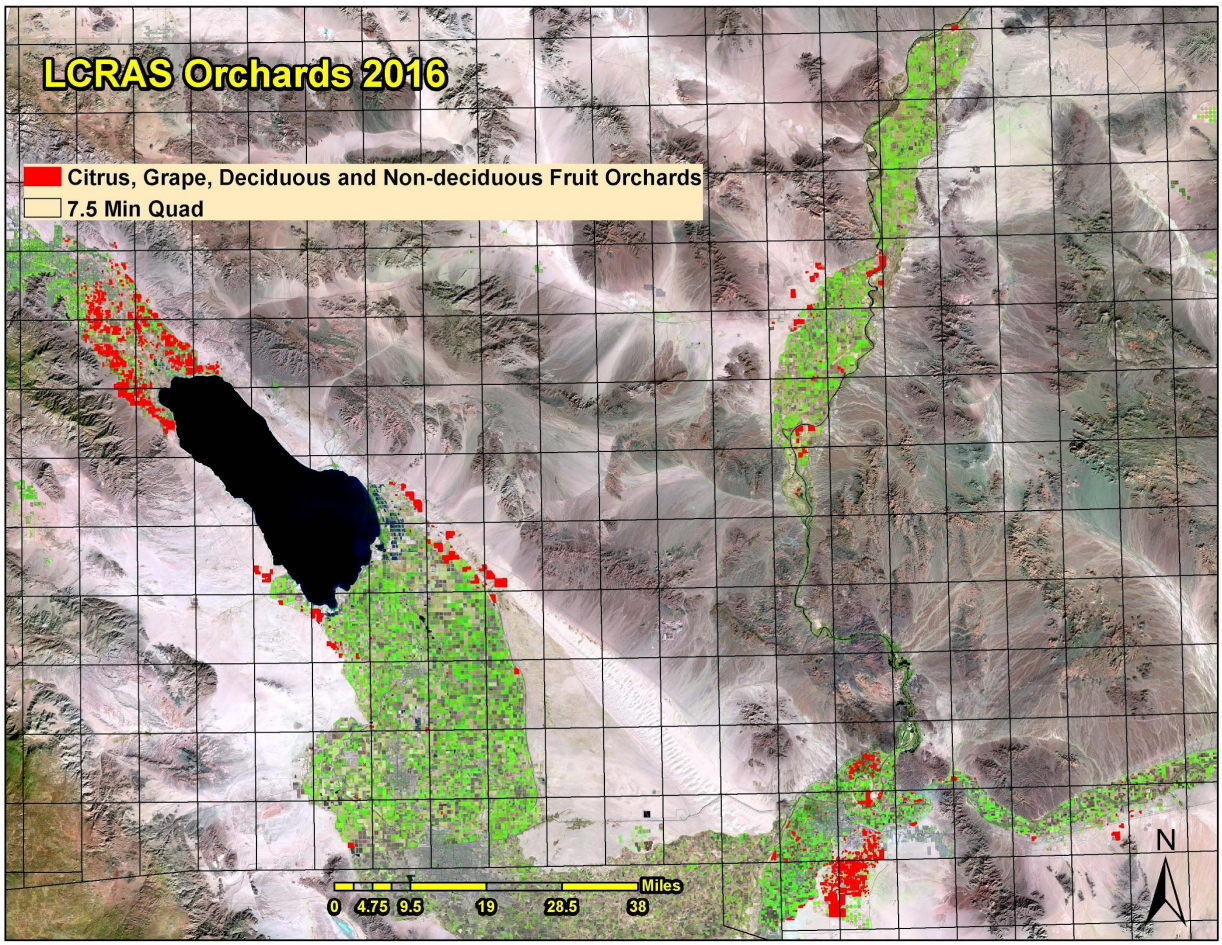



*Photo 05: LandSAT data used for analysis.*

## Tabular Info from SME Interviews

The compilation of the workflows was followed by additional discussions with the SMEs. During those discussions, additional mission-related information was gathered while discussing the differences between the two workflows. The information was sorted and placed into a tabular format for easy comparison.

| | Water Accounting W/O UAS | Water Accounting with UAS |
|---|---|---|
| | **General** | |
| Program Area | Facility Operations (A40) | Facility Operations (A40) |
| Mission Purpose | Gather data on the existence and size of orchards so water usage can be estimated. | Gather data on the existence and size of orchards so water usage can be estimated. |
| Authority/ Requirement | Article V of the Consolidated Decree of the United States Supreme Court in Arizona v. California, 547 U.S. 150 (2006) | Article V of the Consolidated Decree of the United States Supreme Court in Arizona v. California, 547 U.S. 150 (2006) |
| Number of Sites | Area surveyed is throughout the region with a majority of the area within the boundaries of YAO and the CVWD area | Area surveyed is throughout the region with a majority of the area within the boundaries of YAO and the CVWD area |

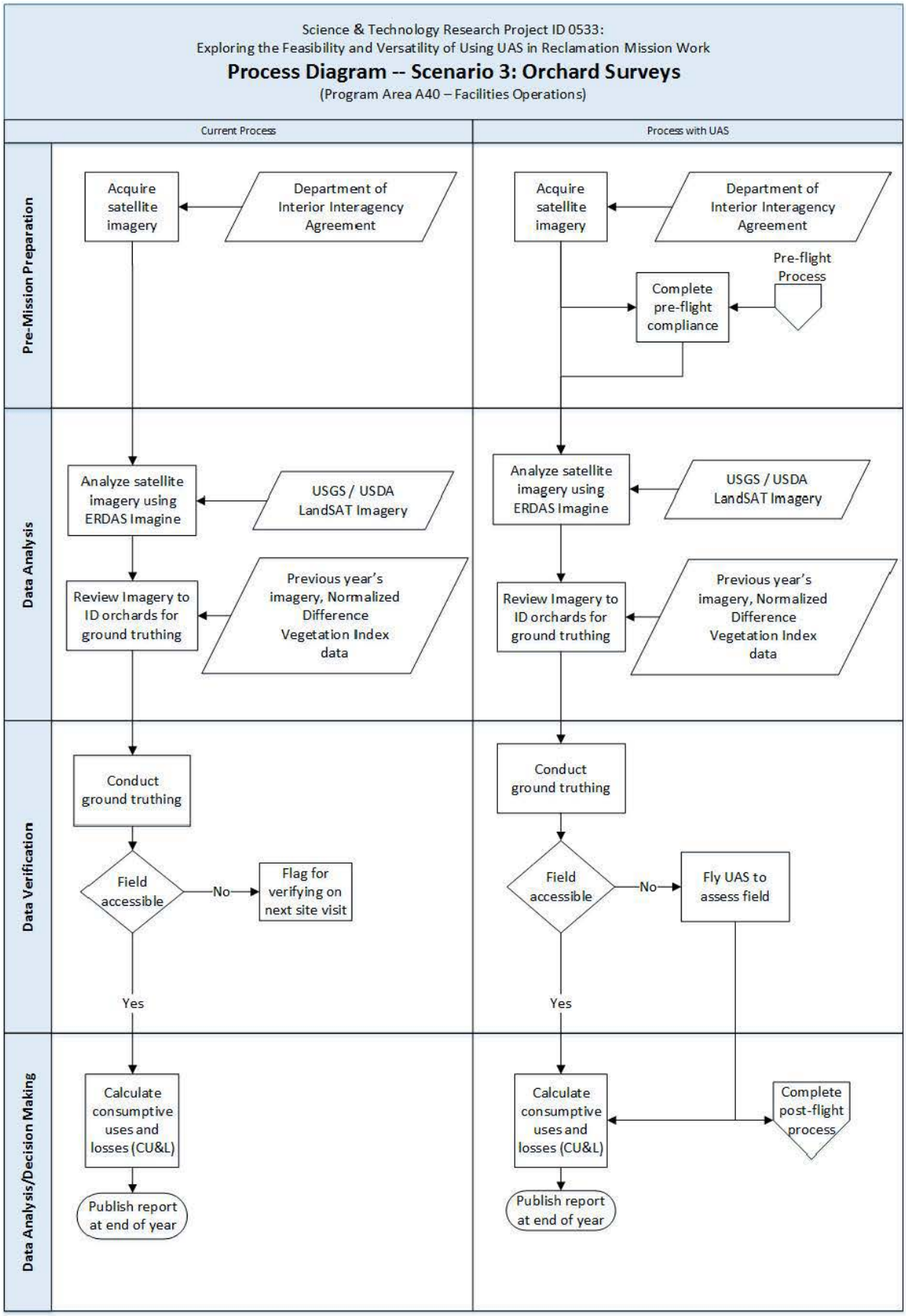
| | | |
|---|---|---|
| Shortest possible duration from planning until data is obtained | Surveys occur year round | Unknown, estimated 30 days to 6 months. While the flight approval process should be fairly straight-forward for most flights, missions over large areas of property owned by many different private citizens and organizations entail additional notification requirements. Once the UAS is procured, the flight approval process should be fairly straight-forward. |
| **Data** | | |
| Data Collected | Presence/absence of an orchard<br>Type of orchard<br>State of orchard (growing, declining) | Presence/absence of an orchard<br>Type of orchard<br>State of orchard (growing, declining) |
| How Data is Collected | Downloaded through a USGS website via Department level IAA between BOR and USGS at no cost to BOR. Ground verifications utilizing a ground crew via GOV. | Primary Data - UAS could be used in lieu of downloading data when UAS is capable of flying extended missions. Multi- and hyperspectral imagery would be collected. Visual verification - UAS can be used to assist ground crew when locked gates or otherwise inaccessible areas are encountered. |
| Data Format | Geospatial Imagery from USDA's National Agriculture Imagery Program (NAIP-USDA), if available; Worldview imagery, or USGS LandSAT imagery.<br>Ground truthing done visually with written notes. | Geospatial Imagery from USDA's National Agriculture Imagery Program (NAIP-USDA), if available; Worldview imagery, or USGS LandSAT imagery.<br>Ground truthing done visually with written notes.<br>UAS - .jpg, .mp4 or similar. |
| Data Quality | Low resolution imagery | High-resolution photography, Multi-spectral imagery if used in place of downloaded imagery |
| Frequency of Collection | Primary data is downloaded 1x per year.<br>Ground truthing done 4 missions per year. | Primary data is downloaded 1x per year.<br>Ground truthing done 4 missions per year. |
| How Data is Processed | Primary Data is processed using ArcGIS by ESRI and ERDAS Imagine by Hexagon Geospatial.<br>Collected data is placed into a set algorithm which calculates estimated water usage | Processing would not change unless data collection went beyond video collection and into sensor technology |
| Parameters Measured | Evapotranspiration<br>Estimated water consumption | Evapotranspiration<br>Estimated water consumption |
| How the Data is Used to Meet Mission Requirements | Data is compiled into total acres by crop type at both irrigation district and state levels. The information is ultimately published for public use. | Data is compiled into total acres by crop type at both irrigation district and state levels. The information is ultimately published for public use. |
| **Crew** | | |
| Number of Crew Members | 1-2 per car, with 5 cars in the field per mission -- a total of 5-10 people per mission. | 2-3, in addition to normal crew of 5-10 people per mission, or a minimum of 7 and maximum of 13 people. |
| Qualifications | Only experience and familiarization required | Experience, remote pilot / spotter training |
| Equipment | Nothing specific | UAS equipment |

| | | |
|---|---|---|
| Vehicles required to accommodate crew and equipment | 4-wheel drive vehicle | 4-wheel drive vehicle with space to carry UAS equipment |
| Interaction with outside entities | There is a general understanding between Reclamation employees and landowners that operators may enter the orchard areas to verify crop information. Orchards that have locked gates are flagged for follow up either later in the year or in the following year. | Verbal (at minimum) notification of landowners of land to be overflown is required for each mission. Information required includes Time/Date, purpose of flyover, and a POC. |
| **Safety** | | |
| Safety for Contractors | N/A | N/A |
| Safety for Employees | Minor risk involved while operating a vehicle to and from orchard. Minor risk of tripping and falling, and heat exposure, while entering an orchard on foot. Areas are generally not remote and communications are available. | Minor risk involved while operating a vehicle to and from orchard. Minor risk to personnel if UAS mishap occurs but reduced risk of tripping/falling if physically entering orchard. Areas are generally not remote and communications are available. |
| Safety for Visitors / General Public | None | Regulations prevent flying over people not involved in the mission; therefore, no additional risk to personnel involved, minor risk to property if a UAS mishap occurs. |

## Process Diagrams for Current Workflows and "With UAS" Workflows

Once the potential uses for UAS to assist with orchard surveys were identified, the current survey workflow was mapped out along with a workflow that could be relevant if UAS were utilized. The workflows were placed side-by-side for easy comparison. The "With UAS Process" was drafted with the assumption that a Reclamation-owned UAS will be utilized.

A PDF of the process diagram below can be found in Appendix 3.


Science & Technology Research Project ID 0533:
Exploring the Feasibility and Versatility of Using UAS in Reclamation Mission Work
Process Diagram -- Scenario 3: Orchard Surveys
(Program Area A40 – Facilities Operations)
Current Process
Process with UAS
Pre-Mission Preparation
Acquire satellite imagery
Department of Interior Interagency Agreement
Acquire satellite imagery
Department of Interior Interagency Agreement
Pre-flight Process
Complete pre-flight compliance
Data Analysis
Analyze satellite imagery using ERDAS Imagine
USGS / USDA LandSAT Imagery
Review Imagery to ID orchards for ground truthing
Previous year's imagery, Normalized Difference Vegetation Index data
Analyze satellite imagery using ERDAS Imagine
USGS / USDA LandSAT Imagery
Review Imagery to ID orchards for ground truthing
Previous year's imagery, Normalized Difference Vegetation Index data
Data Verification
Conduct ground truthing
Field accessible
No
Flag for verifying on next site visit
Yes
Conduct ground truthing
Field accessible
No
Fly UAS to assess field
Yes
Data Analysis/Decision Making
Calculate consumptive uses and losses (CU&L)
Publish report at end of year
Calculate consumptive uses and losses (CU&L)
Complete post-flight process
Publish report at end of year

Review of the mission-related findings identified the following identified several opportunities and barriers. Opportunities included:

- Convenience and more complete data gathering associated with flying the UAS into a field that is inaccessible while staff are physically at the location, rather than requiring staff to return to the same location at a later date to obtain necessary information.

Barriers identified included:

- The nature of ground-truthing missions involves ground truthing staff returning to the same areas four times a year to gather crop data, so if an orchard is not accessible during one trip, the staff will return to that same area on a future trip, and there is a likelihood that it will be accessible during that next trip. Being able to launch a UAS to obtain imagery of an orchard upon finding the site closed does not eliminate travel to the general area on a future trip, so the time saved by utilizing UAS to access inaccessible orchards would be minimal.
- Number of ground truthing missions required per year would not change, and additional personnel would be required for UAS. Assuming one UAS team would accompany the ground truthing crew to survey the locked orchard locations, maximizing that crew's efficiency in the field would require additional coordination, which would increase planning and execution costs.
- Ground truthing gathers data from lands owned by private citizens and organizations, who would need to be notified of a planned UAS overflight. Under the current ground truth process, there is an unwritten understanding that Reclamation employees may enter orchard areas to verify information for water-use calculations. With UAS, notification of landowners is required. Internal Reclamation procedures do not yet exist to notify landowners of a UAS overflight. If Reclamation were to implement a notification process requiring a response from landowners, mission timeframes could be impacted by non-responsive parties.

### Scenario 3 Benefit:Cost Analysis

Findings included:

- People were unwilling to replace staff with UAS; SMEs viewed the tools as additive, supplementing people rather than replacing people. The existing data collection process would occur as it does presently, with the addition of the pilot and spotter and their equipment to the team. The estimated expenses of including UAS on specific orchard survey missions include an initial investment of $81K and annual costs of between $20K and $36K. Without monetizing any qualitative benefits, the net present value of using UAS for orchard surveys over a 5 year period was an estimated -$190k at a discount rate of 3.125%, and -$179k at a discount rate of 7%.
- The SMEs' qualitative assessment of using UAS to support orchard surveys indicated that they felt that using UAS could positively impact the survey process (see green rows in the figure) by reducing risk to employees; supporting efficient, effective, and

transparent decisions; supporting collection of new data, improved data quality and objectivity; supporting improved decision effectiveness; and reducing the difficulty to execute the overall process.

Note: The individual missions each identified costs for the UAS airframe, sensors, accessories, and specialized computer equipment and software, and this approach increased the costs identified for each mission type. In reality, were an airframe and accompanying accessories purchased for one type of mission, that equipment would be used for other missions, which would reduce the overall cost of the equipment. Those leveraged benefits are not identified in the BCA.

Data relating to these analyses can be found in Appendix 4.

## Scenario 4: Environmental Management - Habitat Surveys (Program Area: A30 - Fish & Wildlife Management and Development)

This mission would gather data on factors associated with areas of environmental interest, such as conducting aquatic surveys. The mission for a habitat survey would be to gather data on the layout, makeup, and health of an area of interest. The data is used to determine is the area is suitable for the species living there based on existing models. The mission for an aquatic survey would be to gather data on fish numbers and locations in the lower Colorado River system.

Reclamation conducts terrestrial and aquatic surveys as part of the Lower Colorado River (LCR) Multi-Species Conservation Program (MSCP), meant to balance Colorado River water use while conserving native species and their habitats. Under the MSCP, Reclamation aims to create more than 8,100 acres of habitat for fish and wildlife species, and to augment existing populations of fish with 1.2 million native fish. MSCP activities are funded by a multi-agency partnership; activities are evaluated for their effectiveness in achieving program goals, and reported to a Steering Committee.

### Tabular Info from SME Interviews

The compilation of the workflows was followed by additional discussions with the SMEs. During those discussions, additional mission-related information was gathered while discussing the differences between the two workflows. The information was sorted and placed into a tabular format for easy comparison.

| | **Environmental Management - Aquatic Surveys W/O UAS** | **Environmental Management - Aquatic Surveys with UAS** |
|---|---|---|
| **General** | | |
| Program Area | Resource Management - Fish & Wildlife | Resource Management - Fish & Wildlife |
| Mission purpose | Gather data on fish numbers and locations in the lower Colorado River system. | Gather data on fish numbers and locations in the lower Colorado River system. |

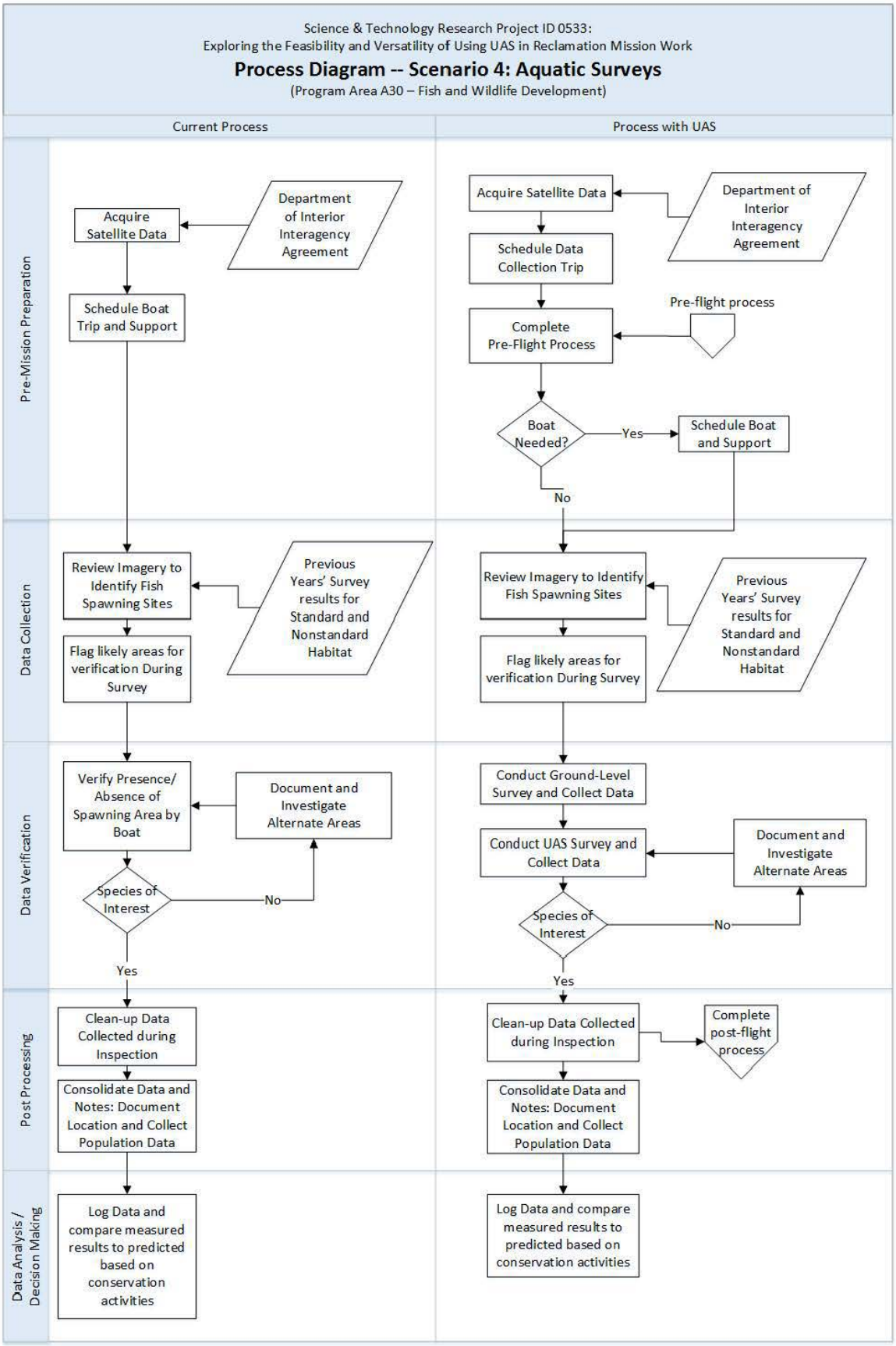
| | | |
|---|---|---|
| Authority/ Requirement | Reclamation conducts aquatic surveys as part of the Lower Colorado River (LCR) Multi-Species Conservation Program (MSCP), meant to balance Colorado River water use while conserving native species and their habitats. | Reclamation conducts aquatic surveys as part of the Lower Colorado River (LCR) Multi-Species Conservation Program (MSCP), meant to balance Colorado River water use while conserving native species and their habitats. |
| Number of Sites | Through every mile CR below Hoover Dam; possibly at least 10 sites<br>* Spawning sites (Lake Mohave): 5<br>* Reach 3 north of Needles bridge: 1<br>* Backwater sites below Needles in Blythe area A7, A10: minimum 2, possibly more<br>* Beal Slough, Beal Lake (turbid - visibility issues)<br>* Imperial Ponds (no fish there yet) | Through every mile CR below Hoover Dam; possibly at least 10 sites<br>* Spawning sites (Lake Mohave): 5<br>* Reach 3 north of Needles bridge: 1<br>* Backwater sites below Needles in Blythe area A7, A10: minimum 2, possibly more<br>* Beal Slough, Beal Lake (turbid - visibility issues)<br>* Imperial Ponds (no fish there yet) |
| Shortest possible duration from planning until data is obtained | 3 days. | Unknown, estimated 30 days based on mission approvals. Once the UAS is procured, the flight approval process should be fairly straight-forward. |
| **Data** | | |
| Data Collected | Location of spawning grounds and number of fish present | Location of spawning grounds and number of fish present. |
| How Data is Collected | Data is collected using satellite imagery from USGS, supplemented by a field crew utilizing a boat or simply wading to record video and/or pictures. | Satellite imagery still used, supported by UAS along with boat trip. Hyper- or Multi-spectral imagery (e.g., FLIR), high resolution video and photographs |
| Data Format | Satellite imagery files, video files (mp4), and georeferenced jpg. | jpg, mp4 |
| Data Quality | Low resolution imagery and video quality based on camera used | High resolution imagery and multi- or hyperspectral (IR) imagery |
| Frequency of Collection | Remote sensing monitoring monthly from Lake Mohave down to reach 4 and 5 | Remote sensing monitoring monthly from Lake Mohave down to reach 4 and 5; UAS supplements info; could give more site specific info. |
| How Data is Processed | Date and time stamp, specific pit tag number; identified in native fish pit tag database; stocking records pulled up to see how long pit tag has been swimming in particular zone of contact (correlates to age info, date of release, hatchery info). Info can be tabulated to look at population estimates. | Same as w/o; looking at IR or NIR possibly in the future; razorback are ectothermic - signature not different from water; would be looking r-g-b photography, possibly future app for additional spectra. |
| Parameters Measured | Pit tag, Age Info, Date of Release, Hatchery, Location of the observation, population size (peterson mark recapture program) | Pit tag, Age Info, Date of Release, Hatchery, Location of the observation, population size (peterson mark recapture program) |
| How the Data is Used to Meet Mission Requirements | Data from aquatic surveys is used to fine tune population models to and asses the health of the species on the habitat. Data is needed to determine if a population is in decline or just moving to non-standard habitat within the reach of the river. Population models are used to inform management decisions and to guide | Data from aquatic surveys is used to fine tune population models to and asses the health of the species on the habitat. Data is needed to determine if a population is in decline or just moving to non-standard habitat within the reach of the river. Population models are used to inform management decisions and to guide |

| | | |
|---|---|---|
| | further conservation work -- if population is improving, they're making the right decisions. | further conservation work -- if population is improving, they're making the right decisions. |
| **Crew** | | |
| Number of Crew Members | 2 people per boat and 2-3 boats or 4-6 people per survey.<br>Sometimes several boats work a given area<br>Field work occurs weekly throughout the year; includes reps from other organizations.<br>Round-ups happen throughout the year for netting. | 5-7 people per survey: 2 people per boat and 2-3 boats; 1 additional person for UAS pilot (spotter would come from existing crew). |
| Qualifications | Boat operator certification | Boat operator certification, remote pilot/spotter training |
| Equipment | Fish identification - handheld devices; Netting -- supplies kept at Cottonwood Cove for year round use;<br>Camping gear, personal safety gear; personnel locators;<br>Remote sensing gear -- antennas ranging from 2x4 square area or 2x6 area w/battery and cable to connect to ground station<br>(submersibles run for about 5 days - they pick up then run data downloads) | Same as without UAS, including UAS equipment |
| Vehicles required to accommodate crew and equipment | Pickups | Pickups and vehicles to carry UAS equipment |
| Interaction with outside entities | N/A | N/A |
| **Safety** | | |
| Safety for Contractors | N/A | N/A |
| Safety for Employees | Typical risks related to field work, such as tripping, falling, etc. | Typical risks related to field work, such as tripping, falling, etc. Using UAS, data can be taken in remote sites while minimizing risks associated with field work; UAS can extend the sightlines of people into remote or inaccessible areas without requiring all of the terrain to be covered on foot. Minor risk of UAS mishap. |
| Safety for Visitors / General Public | N/A | N/A |

## Process Diagrams for Current Workflows and "With UAS" Workflows

Once the potential uses for UAS to assist with aquatic surveys were identified, the current survey workflow was mapped out along with a workflow that could be relevant if UAS were utilized. The workflows were placed side-by-side for easy comparison. The "With UAS Process" was drafted with the assumption that a Reclamation-owned UAS will be utilized.

A PDF of the process diagram below can be found in Appendix 3.


Science & Technology Research Project ID 0533:
Exploring the Feasibility and Versatility of Using UAS in Reclamation Mission Work
Process Diagram -- Scenario 4: Aquatic Surveys
(Program Area A30 – Fish and Wildlife Development)
Current Process
Process with UAS
Pre-Mission Preparation
Acquire Satellite Data
Department of Interior Interagency Agreement
Schedule Boat Trip and Support
Acquire Satellite Data
Department of Interior Interagency Agreement
Schedule Data Collection Trip
Pre-flight process
Complete Pre-Flight Process
Boat Needed?
Yes
Schedule Boat and Support
No
Data Collection
Review Imagery to Identify Fish Spawning Sites
Previous Years' Survey results for Standard and Nonstandard Habitat
Flag likely areas for verification During Survey
Review Imagery to Identify Fish Spawning Sites
Previous Years' Survey results for Standard and Nonstandard Habitat
Flag likely areas for verification During Survey
Data Verification
Verify Presence/ Absence of Spawning Area by Boat
Document and Investigate Alternate Areas
Species of Interest
No
Yes
Conduct Ground-Level Survey and Collect Data
Conduct UAS Survey and Collect Data
Document and Investigate Alternate Areas
Species of Interest
No
Yes
Post Processing
Clean-up Data Collected during Inspection
Consolidate Data and Notes: Document Location and Collect Population Data
Clean-up Data Collected during Inspection
Complete post-flight process
Consolidate Data and Notes: Document Location and Collect Population Data
Data Analysis / Decision Making
Log Data and compare measured results to predicted based on conservation activities
Log Data and compare measured results to predicted based on conservation activities

Review of the mission-related information identified opportunities and barriers to using UAS for aquatic surveys. Opportunities identified included:

- Less disturbance of the habitat, which enables data to be gathered with (1) less disturbance than is experienced when boats enter an area, and (2) better quality and less disturbance than is caused when manned aircraft fly at low altitude.
- Expected greater flexibility in deploying missions to respond to changes in weather or other site conditions, once the Reclamation UAS mission approval process is matured.
- Ability to collect a greater amount and/or quality of data, including ability to gather infrared imagery, and gather more data at a lower cost than is possible through manned flights.

Barriers identified included:

- Little real cost savings from deploying UASs, as missions would occur with or without the technology.
- Lengthy and unclear UAS mission approval process. The current process needed to get approval to utilize a UAS takes a long time; within Reclamation, the process is evolving and not well-understood. This increases the overall mission timeframe and can create planning uncertainties. While the process is expected to become less time consuming over time, it currently represents a barrier to wider UAS use within Reclamation.

### Scenario 4: Benefit:Cost Analysis

Findings included:

- People were unwilling to replace staff with UAS; SMEs viewed the tools as additive, supplementing people rather than replacing people. The existing data collection process would occur as it does presently, with the addition of the pilot and spotter and their equipment to the team. The estimated expenses of including UAS on specific aquatic survey missions include an initial investment of $58K and annual costs of between $36-37K. Without monetizing any qualitative benefits, the net present value of using UAS for aquatic surveys over a 5 year period was an estimated -$224k at a discount rate of 3.125%, and -$208k at a discount rate of 7%
- The SMEs' qualitative assessment of using UAS to support aquatic surveys indicated that they felt that using UAS could slightly positively impact the survey process in the area of data quality/accuracy, decision effectiveness and prospects for improving interagency relationships.

Note: The individual missions each identified costs for the UAS airframe, sensors, accessories, and specialized computer equipment and software, and this approach increased the costs identified for each mission type. In reality, were an airframe and accompanying accessories purchased for one type of mission, that equipment would be used for other missions, which would reduce the overall cost of the equipment. Those leveraged benefits are not identified in the BCA.

Data relating to these analyses can be found in Appendix 4.

# 7. Significant Findings and Recommendations

## Significant Findings

### UAS Mission Approvals

- UAS services can be procured via several methods, including contracting for UAS services or end-product data collection; arranging flights with a cooperating agency; or purchasing and operating a UAS with Reclamation staff. Methods for obtaining UAS services are described in DOI Operational Procedures Memorandum (OPM) 11.
- Vehicle acquisition processes, UAS services acquisitions, and flight approvals are not well outlined processes within Reclamation; this affects the degree of UAS use and approvals for flights. Reclamation staff planning to either purchase UAS or utilize them for missions should plan for long timeframes to secure approval for UAS missions.
- Approvals for flights at Reclamation facilities involve a two-phase process: (1) DOI approval process defined in OPM 11; (2) Reclamation approval process defined in a Reclamation Leadership Memo dated 3/2015.
- To improve expectations of coordination on UAS missions, the approval process defined in the RLT memo could be modified to include SSLE and Safety approvals from staff with organizational jurisdiction for the facilities where proposed flight operations will occur. Currently those staff are not identified within the memo for coordination.

### Potential Missions and Analyses

- Overall findings include that UAS can meet a need for low-altitude, small- to medium-area data collection (to provide access to areas which are inaccessible or unsafe to enter with personnel) utilizing high-resolution cameras and/or advanced sensors (to provide data not available either through manned means or from satellites).
- SMEs did not feel comfortable substituting UAS and sensors for people on missions. That has two consequences:
    - Until UAS are used in missions that build confidence in both their mission utility and the reliability of data they collect, they will continue to be used alongside of, rather than instead of, people in field work. This will limit the technology's full potential to support employee safety.
    - UAS and the related staff will be additional costs to mission performance. Given these conditions, three scenarios identified no avoided costs (savings); one scenario identified avoided costs (savings).
- Interviewees identified high resolution imagery as the key deliverable from UAS data collection. There was limited understanding of how UAS-collected data from advanced sensors and input into analytical tools could be used to support better decision-making. To realize the full utility of UAS-collected data, new software tools and/or training may be needed to allow enhanced analyses and support decision-making.

- The project team associated costs for the UAS airframe, sensors, accessories, and specialized computer equipment and software with each mission. This approach increased the costs identified for each mission, which should be considered a conservative estimate. In reality, were an airframe and accompanying accessories purchased for one type of mission, that equipment would be used for other missions, which would reduce the overall cost of the equipment. Those leveraged benefits are not identified in the BCA.

### Findings Specific to Mission Scenarios

- Scenario 1: Aging Infrastructure - Bridge Inspections (Program Area: A50)
    - In this scenario, UAS is considered useful mainly because of the generally small, concentrated mission areas, potential to improve personnel safety through reduced staff inspections via rope, and potential to utilize data collected from advanced sensors in improved data analysis tools.
    - SMEs expressed that UAS could potentially replace rope team staff in gathering data about bridge conditions and defects. However, they had concerns that inspectors might make lower-quality decisions if they had to base them on UAS-gathered imagery rather than hands- and eyes-on observations.
    - Special focus would be needed to ensure availability of a UAS configuration that could observe upward, underneath a bridge.
- Scenario 2: Inaccessible Features - Rock Fall Inspections (Program Area: A40/50)
    - In this scenario, UAS is considered useful because of the generally small mission areas, potential to improve personnel safety, and potential to utilize data collected from advanced sensors in improved data analysis tools.
    - SMEs expressed that UAS could supplement inspection staff in gathering data about potential rockfall hazards.
    - They felt that better data products could be gathered through using UAS, and that personnel safety could be positively impacted.
- Scenario 3: Water Use Accounting - Orchard Surveys (Program Area: A40).
    - SMEs felt UAS would be less useful in this scenario. Contributing factors include that orchards which are not accessible on one trip may be accessed during a later trip; large mission areas (which would require multiple flights and extensive land-owner notification); potentially extensive team coordination to optimize the use of UAS; and that satellite data is already used early in the data analysis process.
    - SMEs expressed that UAS could supplement orchard survey crews during ground truthing trips, but might not be critical to more efficient or effective completion of the work.
    - Benefits to using UAS would likely be offset by the additional logistical requirements of getting approval to use UAS, requirement to notify landowners

whose property would be overflown during UAS flights, and the coordination required to optimize UAS use during ground truthing trips.

- Scenario 4: Environmental Management - Habitat Surveys (Program Area: A30).
    - In this scenario, UAS is considered useful because UAS can be a less intrusive means to capture data on fish populations in generally small mission areas.
    - Using UAS might mean additional mission costs as using UAS would require field teams of at least two people. SMEs expressed that UAS could supplement aquatic survey crews during data gathering trips, and that UAS could potentially allow less invasive data collection due to their smaller size and quieter operations (compared to manned flights).
    - SMEs also valued the potential increased flexibility of re-scheduling data collection flights in response to near-term weather condition changes.

**Benefit:Cost Analysis Benefits Summary Table.** The project team identified potential qualitative benefits in the areas of risk reduction; environmental, economic and social benefits; data products; and mission execution.

The table below is divided into two sections: Quantitative Benefits (in the form of avoided costs, or savings), and Qualitative Benefits. The project team conducted interviews with the mission SMEs to identify potential avoided costs or savings should UAS be used in missions. During those discussions, the project team asked SMEs to identify potential qualitative benefits. Grey cells in the table indicate no change between the current process and a process using UAS; green boxes indicate a perceived positive change, and orange boxes indicate a perceived negative change.

Table 3. Benefit:Cost Analysis Benefits Summary

| Benefit-Cost Analysis Benefits Summary | | | | |
|---|---|---|---|---|
| **Quantitative Benefits Summary** | **Orchard** | **Aquatic** | **Bridges** | **Rockfall** |
| **Avoided Costs** | **Benefit** | **Benefit** | **Benefit** | **Benefit** |
| Staff time + overtime | $0 | $0 | $ 51,840 | $0 |
| Hazard pay | $0 | $0 | $ 3,240 | $0 |
| Lodging and M&IE costs | $0 | $0 | $0 | $0 |
| Fuel costs | $0 | $0 | $0 | $0 |
| Administrative costs | $0 | $0 | $0 | $0 |
| Equipment operations & maintenance | $0 | $0 | $0 | $0 |
| **Qualitative Benefits Summary** | **Orchard** | **Aquatic** | **Bridges** | **Rockfall** |
| **Risk Reduction** | **Benefit** | **Benefit** | **Benefit** | **Benefit** |
| Reduction in risk to employees | + | 0 | ++ | + |
| Reduction in risk of facility damage or failure | 0 | 0 | 0 | ++ |
| **Environmental, Economic, and Social Benefits** | | | | |
| Reduced carbon footprint (assuming electric UAS) | 0 | 0 | 0 | 0 |
| Efficient, effective, and transparent decisions | + | + | - | ++ |
| Facilitation of interagency relationships | 0 | + | 0 | + |
| **Data Products** | | | | |
| Collection of new data | + | + | + | ++ |
| Improved data quality | + | + | 0 | ++ |
| Improved data objectivity | + | 0 | 0 | ++ |
| Support of open and accessible data initiatives | 0 | 0 | 0 | 0 |
| **Mission Execution** | | | | |
| Mission through-put (beginning to end of mission duration) | 0 | 0 | -- | 0 |
| Difficulty to execute the overall process | + | 0 | -- | - |

## Recommendations

- **Guidance Exists to Support Program Development:** There appears to be sufficient guidance from both OAS and within Reclamation to support Reclamation offices interested in obtaining a UAS and/or conducting missions. In particular, there is extensive public information available about UAS platforms and applications; a range of potential Reclamation missions which could benefit from the addition of UAS; agency Aviation program staff and structure for program oversight; technical staff interested in learning to utilize UAS and data processing tools, and program managers interested in benefits which can be derived from using UAS in mission work. Reclamation offices wishing to invest the time and resources into a UAS program should be able to follow a fairly straight-forward path.
- **Program Management Models:** Reclamation should consider how to manage its UAS program(s) and communicate that information. Example management models include: (1) Each Directorate manages its own UAS Program (as in the way the Agency manages its Rope Teams); (2) Semi-Centralized Program Management -- two or three Regions house

UAS programs and offer services to Reclamation (as in the way Reclamation handles the Dive Teams); (3) Centralized management from a single office -- a single office maintains a program and offers services to Reclamation (as in the way Reclamation handles the CCTV program). Potential decision criteria to analyze how to manage the program(s) include the costs to invest in and maintain a UAS platform and sensors, costs to obtain and maintain staff certifications and expertise, and need and desired depth of agency expertise in this area.

- **Flight Approvals:** An appropriate person or group should solicit feedback on the Reclamation UAS mission approval process described in the RLT Memo to gather lessons learned from recent flights, and the updated information should be distributed to Reclamation staff.
- **Mission Expenses vs. Savings:** When adopting UAS, managers should plan to incur additional costs which are anticipated to be offset by qualitative benefits to personnel safety and in the form of higher-quality data to develop more advanced analysis tools than currently exist. As more experience with missions creates awareness of how savings could be generated, it is possible that more expenses could be offset by financial savings.
- **Inaccessible Features Inspections Missions:** Reclamation offices responsible for assessing and mitigating rockfall hazards should consider exploring how UAS could be included as a tool to improve personnel safety and decision making effectiveness. UAS could be used to reduce the time personnel spend conducting work on ropes, while creating a more extensive dataset to use in assessing hazards.
- **Facilities Inspections Missions:** Reclamation offices responsible for operating and maintaining dams and bridges should consider adopting UAS and using the systems on facilities inspection missions. Other possible uses include inspections of facilities such as roofs, transformers, or towers, potentially using infrared or thermal sensing. Higher-quality data obtained would be used to help offices identify maintenance and repair needs and avoid/minimize impacts to mission operations.
- **Survey and Geospatial Applications**: Reclamation offices collecting Survey and Geospatial data should consider adopting UAS to utilize the potential to quickly deliver high temporal and spatial resolution information. Real-time data collection for fast data acquisition, transmission, and processing could benefit the surveyors and geospatial programs by providing up to date information.
- **Data Analysis Tools:** UAS data collection can return large amounts and types of data, which need to be post-processed, managed and incorporated into tools to support analysis and decision-making. Reclamation offices planning to optimize UAS-collected data should budget for sufficient IT hardware, software, training and development time for staff to gain needed expertise. There will also need to be time invested in building awareness among program managers about what advanced tools are available and how they can be used to support analysis and decision-making.

- **Information Sharing on Using UAS in Reclamation:** Reclamation should re-convene the Reclamation UAS Community of Interest to share information about UAS best practices, missions, technology, and tools. The existing Reclamation UAS SharePoint site (https://teamsdrosp.bor.doi.net/tsc/uas/Pages/default.aspx) should be modified to include a message board or wiki option to facilitate information sharing among the Reclamation UAS community members.

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# 9. Appendices

Appendix 1: Flight Approvals

Appendix 2: Information for Starting a UAS Program and Obtaining UAS Equipment

Appendix 3: Mission Process Diagrams

Appendix 4: Benefit Cost Analysis Information

# Appendix 1: Flight Approval Process Flows

## DOI Requirements for UAS Flights

*(Reference: Kristin Swoboda, Pacific Northwest Region)*

### Vehicle Acquisition and Staff Preparation

1. The DOI entity must have their Operational Testing and Evaluation (OT&E) proposal in place with OAS.
2. Funding must be transferred to OAS in order to acquire DOI authorized UAS.
3. Staff must participate in DOI UAS training

### Pre-Flight Compliance for Each Flight (DOI Procedures; see section Reclamation Procedures for UAS Flights, listing additional approval requirements for individual flights)

1. All flights must be compliant with DOI OPM-11
2. Flights must be in compliance with OAS and FAA regulations
3. Project Aviation Safety Plans must be completed
4. COA's or G-Notifications filed with the FAA
5. NOTAMs filed with the FAA
6. Communications and Safety briefing

### Flight Procedures

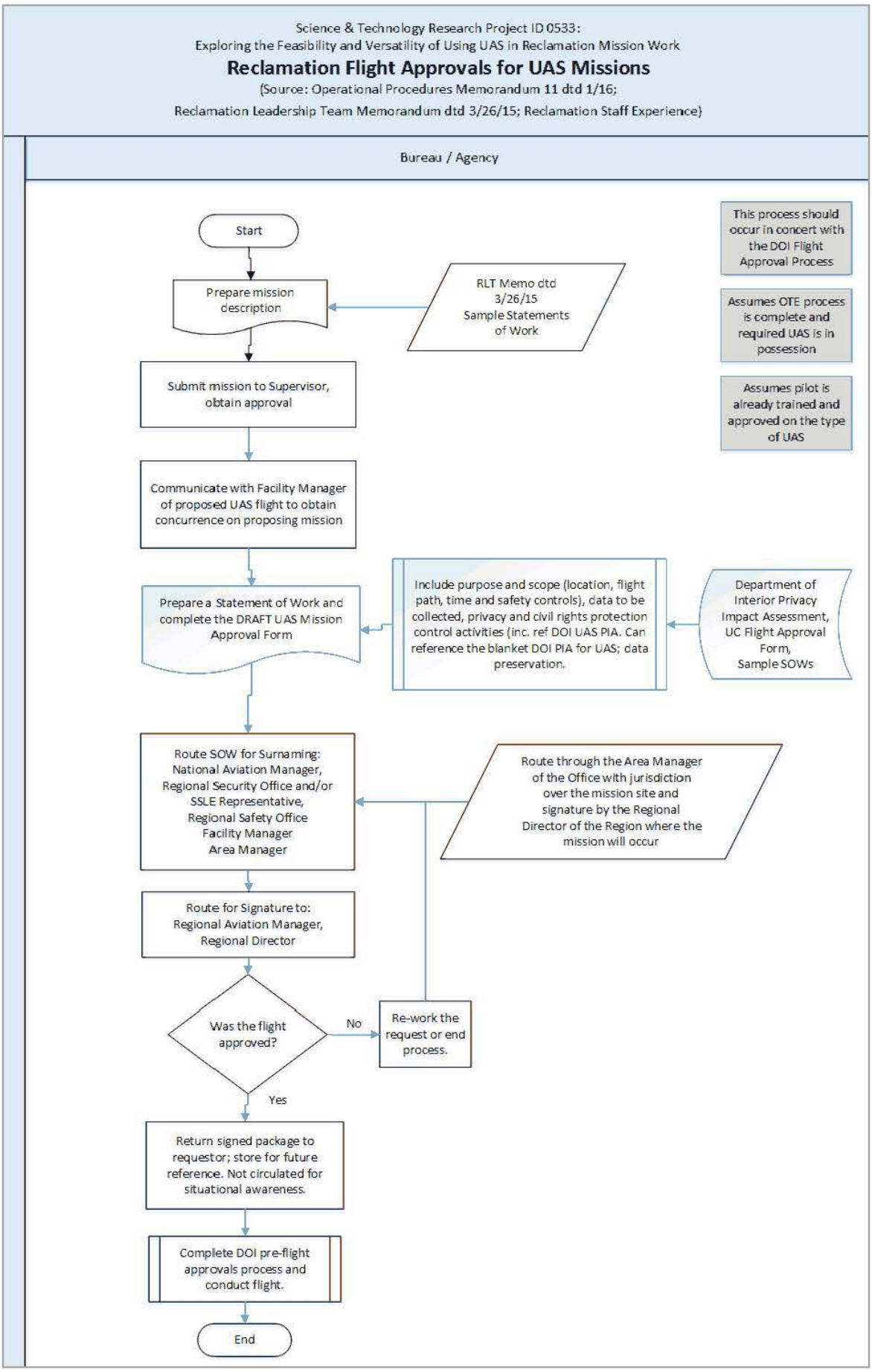
1. Pre-flight checks
2. Fly using proper overlap and sidelap calculations--dependent of camera/sensor used and flight altitude
3. Data management of acquired data during flight
4. After action briefing

### Post-Flight

1. Data management of acquired data
    a. Post-processing---Photoscan, Pix4D, drone2map, etc
    b. Data processing reports
2. Flight Use report to OAS
3. Flight Use report to FAA

## Reclamation Requirements for UAS Flights

The Reclamation approval process is evolving and must be completed in addition to the DOI flight approval procedures. An approval process workflow was prepared and is included below; the source Visio file can be found in Appendix 1 (*Process Flows - Approvals.pdf*). The procedure is based on the RLT Memo Unmanned Aircraft Systems dated 3/26/2015, and lessons learned from three UAS flights conducted by cooperating agencies at Reclamation's request. The primary point of contact for this procedure is Matthew Klein at the Denver Technical Services Center.


Science & Technology Research Project ID 0533:
Exploring the Feasibility and Versatility of Using UAS in Reclamation Mission Work
Reclamation Flight Approvals for UAS Missions
(Source: Operational Procedures Memorandum 11 dtd 1/16;
Reclamation Leadership Team Memorandum dtd 3/26/15; Reclamation Staff Experience)
Bureau / Agency
Start
Prepare mission description
RLT Memo dtd 3/26/15 Sample Statements of Work
This process should occur in concert with the DOI Flight Approval Process
Assumes OTE process is complete and required UAS is in possession
Assumes pilot is already trained and approved on the type of UAS
Submit mission to Supervisor, obtain approval
Communicate with Facility Manager of proposed UAS flight to obtain concurrence on proposing mission
Prepare a Statement of Work and complete the DRAFT UAS Mission Approval Form
Include purpose and scope (location, flight path, time and safety controls), data to be collected, privacy and civil rights protection control activities (inc. ref DOI UAS PIA. Can reference the blanket DOI PIA for UAS; data preservation.
Department of Interior Privacy Impact Assessment, UC Flight Approval Form, Sample SOWs
Route SOW for Surnaming: National Aviation Manager, Regional Security Office and/or SSLE Representative, Regional Safety Office Facility Manager Area Manager
Route through the Area Manager of the Office with jurisdiction over the mission site and signature by the Regional Director of the Region where the mission will occur
Route for Signature to: Regional Aviation Manager, Regional Director
Was the flight approved?
No
Re-work the request or end process.
Yes
Return signed package to requestor; store for future reference. Not circulated for situational awareness.
Complete DOI pre-flight approvals process and conduct flight.
End

# Appendix 2: Information for Starting a UAS Program and Obtaining UAS Equipment

## Information on Starting a UAS Program

The Department has developed a memorandum pertaining to this topic and which contains useful links to additional information. The memo can be found in Appendix 2 (*DOI sUAS Startup Guidance Package 2016_07_28.pdf*). Appendix 2 also contains a presentation and white paper from the USGS entitled *How to Develop and Sustain a Successful UAS Program for Enhanced Science, Safety and Savings.*

## Updates to DOI Operational Procedures Memorandum 11 to Reflect FAA Part 107

*Source: Kristin Swoboda.* In January, the re-write of OPM-11 for DOI UAS operations will be in effect. These new changes to the OPM generate different requirements for becoming a DOI UAS pilot operator.

What this means for future UAS pilots:

- FAA Class 2 Medical requirement for Commercial pilots is no longer necessary.
- DOI UAS pilots will be required to take the FAA Remote Pilot knowledge test.
- The FAA UAS Pilot license is required before attending a DOI UAS Pilot training course.

To prepare for the remote pilot test, Reclamation staff can visit the following links for study material:

- FAA's guidance and suggested study material. This site has a user friendly collection of resources relating to remote pilot certification. It also contains valuable practice tests that will help with breaking down the material for the FAA knowledge test. WARNING: If you use only the FAA practice tests to study, there will missing material that may end up in your FAA knowledge test.
- 3DR FAA Part 107 - Remote Drone Pilot License Resources.

## Vehicles Approved for Purchase by the Department of the Interior

The following vehicles have been approved for purchase and use by the DOI. This list is current as of November 2016 and is subject to future updates; an updated list of approved vehicles is maintained at the DOI UAS fleet page on the DOI's UAS webpage.

Appendix 2: Table 1

| | **Fixed-Wing Falcon** | **Pulse Vapor 55 Helicopter** | **Falcon Hover** | **3DR Solo** |
|---|---|---|---|---|
| **Manufacturer** | Falcon Unmanned | Pulse Aerospace | Falcon Unmanned | 3D Robotics |
| **Take off Weight (lbs)** | up to 11lbs | up to 55lbs | up to 7.5lbs | up to 3.9lbs |

| | | | | |
|---|---|---|---|---|
| **Payload Capacity (lbs)** | up to 2.5lbs | up to 10lbs | up to 2.5lbs | up to 1.8lbs |
| **Flight Time (min)** | 60+ Min. (Mission dependent) | 45-60 Min. (Mission dependent) | 20-25+ Min. (Mission dependent) | 15-20 Min. (Mission dependent) |
| **Comm Range (Miles)** | 6+ Miles (terrain / antenna dependent) | 5 Miles (terrain / antenna dependent) | 6+ Miles (terrain / antenna dependent) | .6 Miles (terrain / antenna dependent) |
| **Cost** | $41,900.00 | $143,900.00 | $33,900.00 | $1,700.00 |

# Appendix 3: Mission Process Flows

See attached Process Diagrams.

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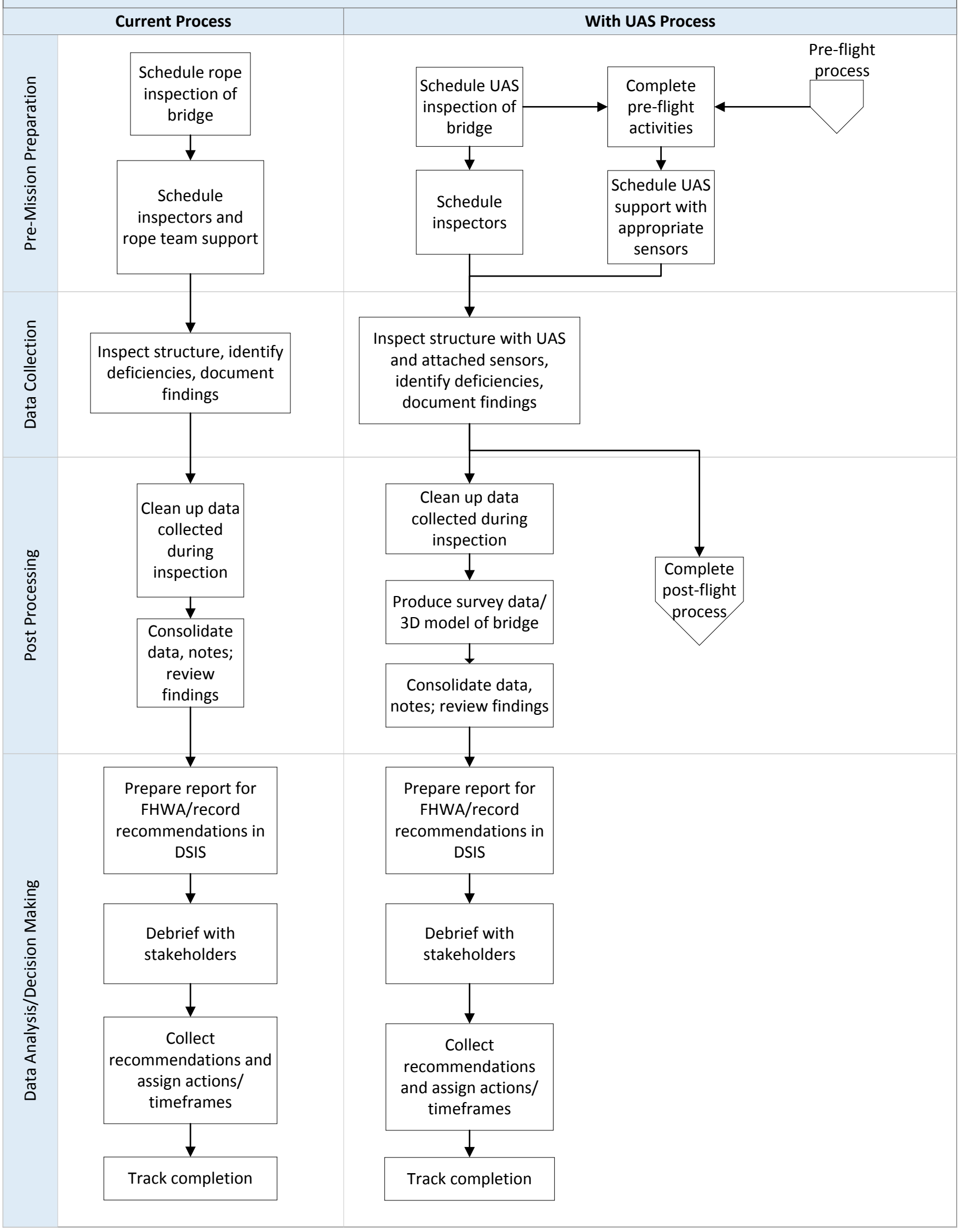
# Process Diagram -- Scenario 1: Bridge Inspections

(Program Area A50 – Facilities Maintenance & Rehabilitation)



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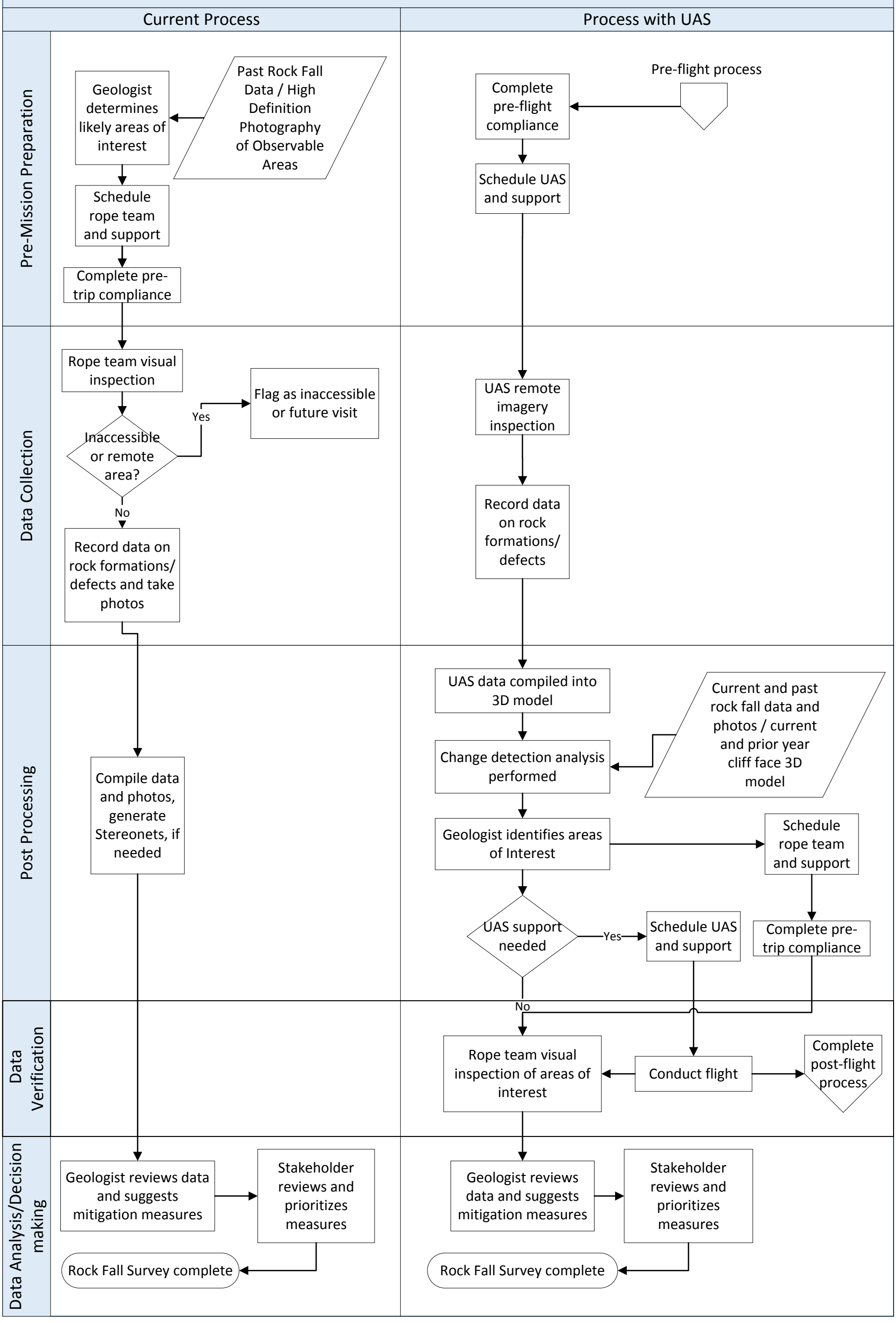
# Process Diagram -- Scenario 2: Rockfall Inspections

(Program Areas A40, A50 – Facilities Operations, Maintenance & Rehabilitation)



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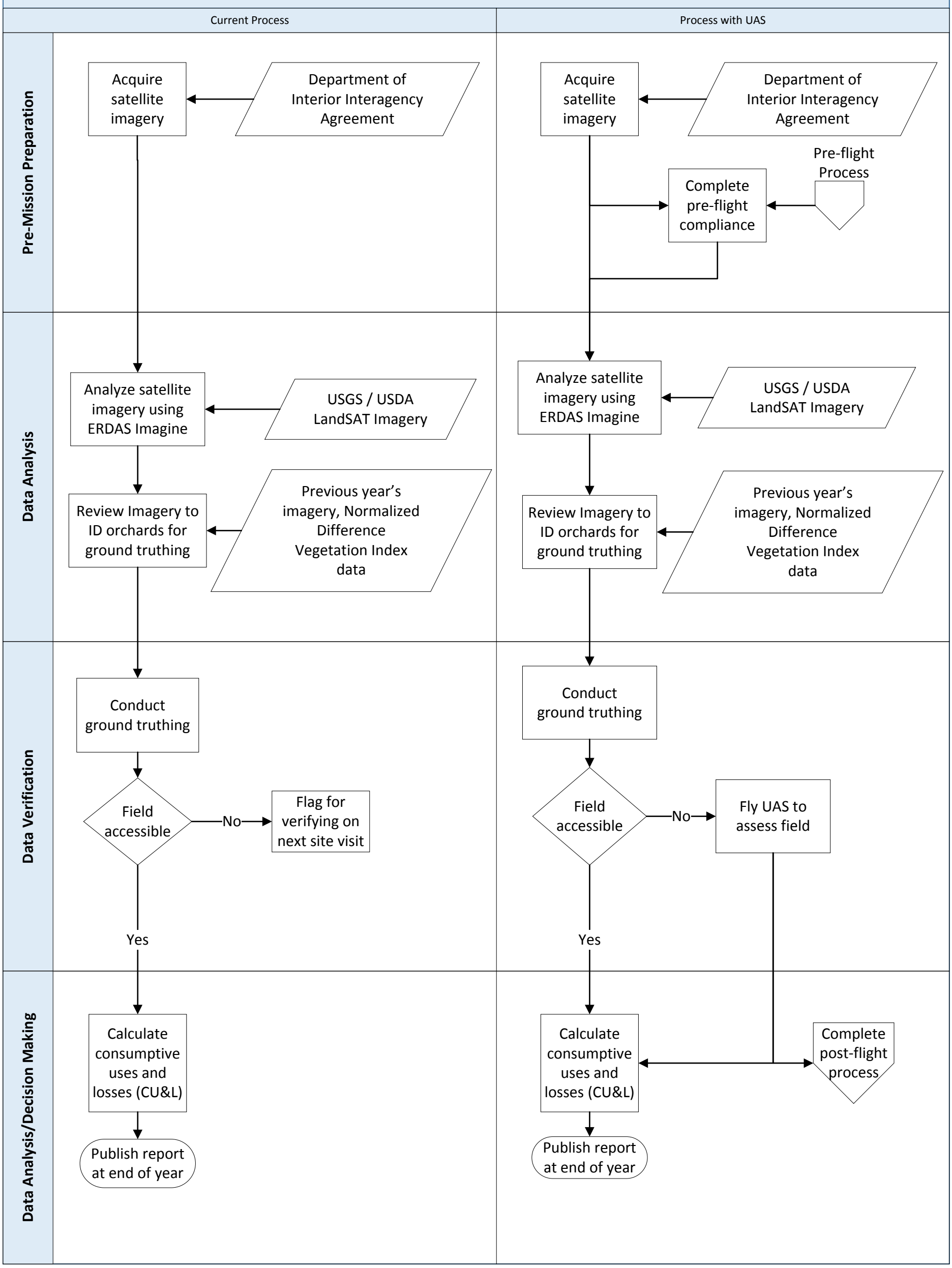
# Process Diagram -- Scenario 3: Orchard Surveys

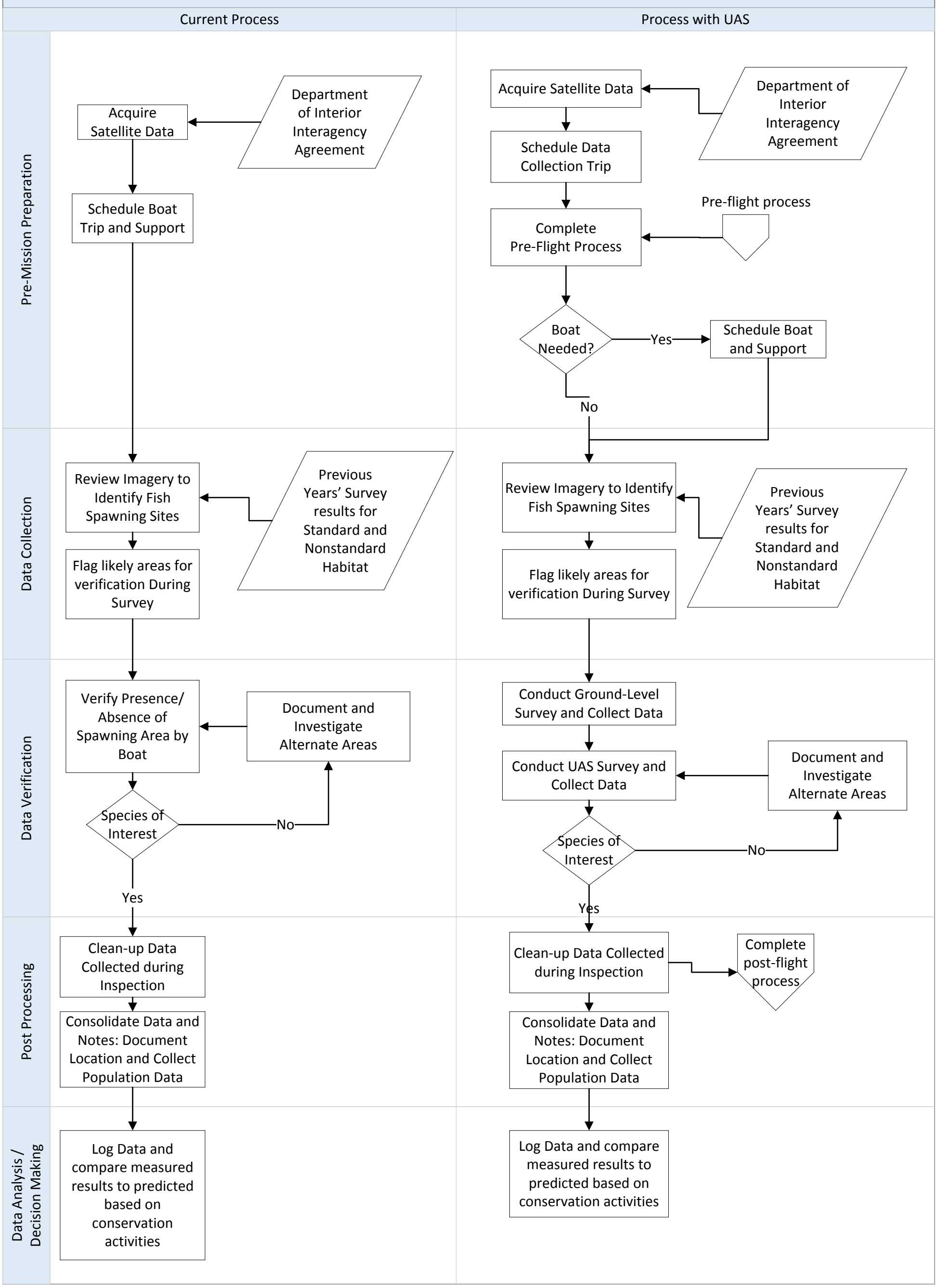
(Program Area A40 – Facilities Operations)



Science & Technology Research Project ID 0533:
Exploring the Feasibility and Versatility of Using UAS in Reclamation Mission Work

# Process Diagram -- Scenario 4: Aquatic Surveys

(Program Area A30 – Fish and Wildlife Development)



# Appendix 4: Benefit:Cost Analysis Information and Tables

## Benefit:Cost Analysis General Principles

Office of Management and Budget (OMB) Circular No. A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," provides guidance on the preparation of benefit-cost analysis; its goal is to "promote efficient resource allocation through well-informed decision-making by the Federal Government." Benefit-cost analysis is a systematic quantitative assessment of the desirability of programs or projects, which is generally indicated by a positive net present value. Efforts to measure net present value, however, may produce more qualitative than quantitative data; in that case, decision-makers will rely on other measures of the effects of a program. This benefit-cost analysis seeks to support UAS-related decision-making by identifying qualitative and quantitative benefits and costs of using UAS in mission work, from an economic and financial perspective.

## Data Collection and Analysis Process

### Spreadsheet Design

After a preliminary review of the theoretical benefits and costs of using UAS in mission work, the LC Region's staff Economist developed a Benefit-Cost Analysis (BCA) Summary spreadsheet template to be populated through discussions with mission SMEs. For each mission, this BCA Summary covers an investment year (Year 0) and Years 1 through 5, which is assumed to be the complete life-cycle of a UAS. Benefits and operating costs would begin to accrue in Year 1, and the values entered represent an entire year. In every cell where a value was desired, we populated $1.00 as a placeholder in the template.

### Quantitative Benefits Analysis

Benefits are presented first, beginning with avoided costs; these are actual financial expenses that the agency would have incurred in the absence of UAS. Where UAS replaces other resources in the completion of a task, or enables us to operate at a lower intensity, there is an opportunity for direct cost savings which we attribute to the UAS program as a benefit.

We anticipated that respondents would not find the BCA Summary an approachable tool for populating avoided costs, and decided to request the data in more manageable increments, using an Avoided Costs Worksheet. For each mission, we asked SMEs to consider their current practice, their estimated practice with UAS, and the difference between the two in estimating their:

- Number of Missions/Year
- Administrative Costs/Mission
- Number of Personnel/Mission
- Average Fully Burdened Hourly Salary/Person
- Vehicle Miles Driven/Mission
- Boat Miles Driven/Mission

- Flight Time/Mission
- Average Fuel Purchases/Mission
- M&IE and Lodging Costs/Person/Mission
- Number of Regular Hours Worked/Person/Mission
- Number of Overtime Hours Worked/Person/Mission
- Number of Hazard Pay Hours/Person/Mission
- Special Equipment Maintenance Costs/Mission
- Probability of Death/Person/Mission, in Millionths (Micromorts)

During our data-gathering meetings with SMEs, we prompted them with some of the following questions:

- Can you replace any traditional site visit with UAS Flights?
- Are there arrangements you wouldn't make, like travel, or equipment or maps that you wouldn't prepare?
- Can you perform the mission with fewer staff, or the same number of staff for fewer hours?
- Are there opportunities to replace a specialist with a technician?
- Are there possible reductions in the length of trips (either time or distance) with UAS?
- Could UAS-related efficiencies help reduce overtime expenses?
- Is it possible to replace some number of hazardous tasks (rope access, SCUBA) with UAS? What activities qualify?
- Consider the costs of climbing gear, dive gear, or tool use/rental/replacement/repairs that are use-dependent and could be reduced.
- Referencing https://en.wikipedia.org/wiki/Micromort, if SCUBA has a probability of death of 10/1,000,000 per dive (0.000008) and base jumping is 430/1,000,000 per jump (0.00043), how do you rate the risks of your mission?

### Calculating Avoided Costs

The way avoided costs are calculated would be determined for each mission individually after meeting with SMEs and discussing how they see their mission work changing with UAS; an avoided cost relating to staff time (for example) could be attained through a reduction in staff, a reduction in hours worked, shorter or fewer trips, or by using technicians instead of specialists. A formula example for hazard pay not incurred in a year as a result of UAS was shown as follows for discussion purposes:

> *Reduction in Number of Missions per Year * Number of People Who Would Have Worked * Average Staff Salary * 0.25 (Hazard Multiplier) * Hours of Hazard Pay per Person per Mission*

### Qualitative Benefits Analysis

Other types of projected benefits from using UAS in mission work are harder to quantify, but are critical to the decision to employ UAS. Again the team felt that the BCA Summary spreadsheet would not provide enough guidance to SMEs in attempting to answer these questions, so we developed a Qualitative Factors Assessment to be used in discussing benefits other than avoided costs. On a scale of 1-5, with current practice always rating a 3, SMEs were asked to score their

"with UAS" scenario against their current practice using the following factors, which loosely corresponded to the BCA Summary:

- Employee/contractor/visitor safety
  - Consider how we decide to assign tasks to humans vs. machines. Risk reduction benefits, an expected value, depend on our monetization of a life and the estimated probability of a fatality. Can UAS change that risk profile?
- Risk to agency operations
  - Thinking of a facility or feature, can UAS reduce the probability of failure, such as a rockfall on generation equipment or the collapse of a bridge?
- Data Quality/Accuracy
  - More precise ET maps, variations in plant nutrient values, additional spectra, precision agriculture?
  - Consider the data density needed for the mission (photos vs. point clouds vs. photogrammetry).
  - UAS data could improve upon the subjective judgement of personnel, who may lack full information.
- Decision Effectiveness
  - Think rapid responses to vulnerabilities or opportunities, and funding applied where it is needed most.
- Prospects for improving interagency relationships
  - Can we build or enhance communities of practice through sharing a UAS or its data products? Can we improve our accountability to stakeholders, such as MSCP partners or water users?
- Contribution to Open Data initiatives
  - Could data availability assist other public operations, such as fire fighting? What about concessionaires who use our lands or facilities and want to understand their exposure to risks such as rockfalls?
- Mission through-put (beginning to end of mission duration)
- Difficulty to execute the overall process

Those scores and the qualitative data gathered through the discussion process identified the benefits applicable to each mission, as envisioned by SMEs, and indicated the magnitude. A single "+" in the BCA Summary indicates a moderate unquantifiable benefit, while a "++" indicates a significant unquantifiable benefit. The rare "-" or "--" would indicate a theoretical benefit that SMEs actually considered to be a drawback for their specific mission.

The qualitative data gathered about employee safety could also be supplemented by a quantitative valuation of reduced mortality risk, for missions where UAS can take the place of a human in performing hazardous tasks (or where UAS otherwise reduces the harm faced by a human). For this reason, and to promote discussion, we explained the concept of a micromort (a 1-in-1,000,000 risk of death) to SMEs and asked them to assess their missions for mortality risk both before and after UAS. The change is what we would be interested in. For example, if a mission staff member is estimated to face a 3-micromort risk (3/1,000,000 or 0.000003) in the

performance of a task, but UAS can perform the task instead, the agency has avoided a 0.0003% chance of an employee fatality. Multiplying that probability by the value of a statistical life yields a monetized value attributable to UAS in that role. The Environmental Protection Agency (EPA) recommends using $7,400,000 (in 2006 dollars) as the value of a statistical life in all current benefits analyses. This value can be indexed to $8,704,644 (2016 dollars) by using the Gross Domestic Product Implicit Price Deflator. EPA's value of a statistical life applies broadly to the population. Given that we are dealing with a small group of people who are highly trained and known personally to us, and that a fatality could significantly impair the continued operation of Reclamation programs, the agency might choose to use a higher value. However, in this example, a risk of 0.000003 * $8,704,644 in statistical life value = $26.11 in avoided mortality risk per person, per task. Monetizing this benefit may not convey as much information to decision-makers as a qualitative discussion.

For mission scenarios where adoption of UAS would result in a reduction in fuel purchases, Reclamation's carbon footprint would also be reduced, providing an additional monetizable benefit. In 2013, in a report titled "Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," the Interagency Working Group on Social Cost of Carbon estimated a range of values ($12-$113/metric ton in 2016) for the social benefits of reducing carbon dioxide emissions. EPA suggests that consuming a gallon of gasoline produces $8.887 \times 10^{-3}$ metric tons of carbon dioxide. In that case, every gallon of gas conserved through the UAS program would produce a social benefit of $0.11-$1.00.

### Analysis of Costs

We identified cost factors to be considered for using UAS in Reclamation mission work; they included:

- Performance and data requirements for various types of work
  - Ability to capture images of a rock face
  - Sufficient flight time to canvas an entire orchard
- System operational costs
  - Batteries
  - Vehicle replacement
- Hardware requirements
  - Type of system, payload, and sensors
- Software requirements
  - Specific software dependent on type of work
- Compliance requirements
  - Pre-mission coordination and approval
  - Pilot medical examination
  - Pilot and ground crew training
  - Specific software training
  - Hangar storage and security

- Desired deliverables and post-mission analysis

### Evaluation of UAS Mission Scenarios through Benefit:Cost Analysis

The BCA Summary spreadsheet subtracts annual monetized costs from monetized benefits to derive a value for net benefits in Years 0 through 5 (note that we expect to see a negative net benefit in Year 0 for every mission; investments must be made to establish a program before any benefits can be generated). A UAS mission's Net Present Value is calculated by discounting the future stream of annual net benefits to the present time as follows:

*Net Present Value = Future Value / (1 + Discount Rate) ^ Number of Years*

Net Present Value reflects the benefits of UAS for the mission, our ability to monetize those benefits within the scope of this study, and the timing of benefits and costs. Some missions may have negative net benefits in every year because the benefits identified by SMEs are non-monetary. Alternatively, a mission with monetized benefits may have a negative overall Net Present Value because future benefits are significantly discounted relative to the initial investment. The choice of a discount rate reflects the time value of money; costs and benefits are worth more in the present than in the future, and a higher discount rate accentuates this effect. Because the time value of money varies in magnitude depending on whether benefits accrue to the Federal government internally, or to society as a whole, we have calculated Net Present Value using two real rates, 3.125% and 7%, to provide a sensitivity analysis.

Given the difficulty of monetizing benefits, decision-makers should carefully consider Net Present Value only in the context of the qualitative data collected for this report; both are presented in the following mission-specific discussions and tables (which are available in Excel upon request).

# Bridge Inspections

## Benefit-Cost Analysis Summary

| Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| **Avoided Costs** | | | | | | |
| Staff time | $0 | $51,840 | $51,840 | $51,840 | $51,840 | $51,840 |
| Hazard pay | $0 | $3,240 | $3,240 | $3,240 | $3,240 | $3,240 |
| Lodging and M&IE costs | $0 | $1,238 | $1,238 | $1,238 | $1,238 | $1,238 |
| Fuel costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Administrative costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Equipment operations & maintenance | $0 | $0 | $0 | $0 | $0 | $0 |
| **Risk Reduction** | | | | | | |
| Reduction in risk to employees | $0 | $1,393 | $1,393 | $1,393 | $1,393 | $1,393 |
| Reduction in risk of facility damage or failure | $0 | $0 | $0 | $0 | $0 | $0 |
| **Environmental, Economic, and Social Benefits** | | | | | | |
| Reduced carbon footprint (assuming electric UAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Efficient, effective, and transparent decisions | $0 | - | - | - | - | - |
| Facilitation of interagency relationships | $0 | $0 | $0 | $0 | $0 | $0 |
| **Data Products** | | | | | | |
| Collection of new data | $0 | + | + | + | + | + |
| Improved data quality | $0 | $0 | $0 | $0 | $0 | $0 |
| Improved data objectivity | $0 | $0 | $0 | $0 | $0 | $0 |
| Support of open and accessible data initiatives | $0 | $0 | $0 | $0 | $0 | $0 |
| Total Benefits by Year | $0 | $57,711 | $57,711 | $57,711 | $57,711 | $57,711 |

| Costs by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| **UAS Program Costs** | | | | | | |
| Airframe | $33,900 | $0 | $0 | $0 | $0 | $0 |
| Accessories | $2,400 | $0 | $0 | $0 | $0 | $0 |
| Sensors/Cameras | $11,000 | $0 | $0 | $0 | $0 | $0 |
| Training | $3,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Licensing/certification | $1,000 | $500 | $500 | $500 | $500 | $500 |
| **Mission-Specific Operations** | | | | | | |
| Pilot and spotter staff time | $0 | $18,620 | $18,620 | $18,620 | $18,620 | $18,620 |
| Pilot and spotter lodging and M&IE costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Pilot and spotter fuel costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Maintenance | $0 | $500 | $500 | $500 | $500 | $500 |
| Replacement Parts | $0 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Pre-flight compliance (approvals) | $0 | $3,000 | $3,000 | $2,000 | $2,000 | $2,000 |
| Contracting (333, OAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Public involvement / Notification | $0 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 |
| **Data Products** | | | | | | |
| Specialized computer(s) | $8,000 | $0 | $0 | $8,000 | $0 | $0 |
| Software purchase, licensing, and updates | $5,000 | $2,000 | $2,000 | $5,000 | $2,000 | $2,000 |
| Training | $5,000 | $0 | $0 | $5,000 | $0 | $0 |
| Staff time for new data analyses | $5,000 | $3,000 | $3,000 | $3,000 | $3,000 | $3,000 |
| Total Costs by Year | $74,300 | $32,620 | $32,620 | $47,620 | $31,620 | $31,620 |

| Net Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Annual Net Benefits (Costs) | -$74,300 | $25,091 | $25,091 | $10,091 | $26,091 | $26,091 |

| Evaluation Metrics | |
|---|---|
| Net Present Value at a 3.125% Discount Rate | $28,263 + unquantified benefits |
| Net Present Value at a 7% Discount Rate | $17,808 + unquantified benefits |

Bridge inspection is the only scenario where mission staff could estimate that UAS would enable them to complete their mission using fewer conventional resources; therefore, it is the only scenario to identify avoided costs as a benefit of UAS. Those avoided costs arise through the following assumptions:

- Staff time
  - Four rope-access personnel, at $135/hour (fully burdened), will no longer be part of the 4 annual missions, working 24 hours per mission; instead, 2 UAS staff are assumed to take their place for the same number of hours, at $96.98/hour. Two inspectors will be present for each mission, with or without UAS; they are omitted from the analysis to focus attention on the variable resources and to avoid introducing error in making assumptions about their salaries
- Hazard pay
  - For eight hours of each mission, rope access staff would have collected hazard pay, a 25% premium on their base salary; the base salary is assumed to be 75% of the fully burdened rate
- Lodging and M&IE costs
  - Representative locations were chosen to estimate the cost for 4 annual inspections, recognizing that specific bridges are actually visited on a biennial cycle
    - 2 at Hoover Dam
      - No travel required
    - 1 at Parker Dam and 1 in Yuma
      - Assume two travel days at 75% of the $51 M&IE rate, and one full day at $51, and
      - 2 nights at $91 for lodging
  - Four rope-access personnel will be replaced with 2 UAS personnel at the same per-person travel cost; therefore, we've shown only the net avoided cost as a benefit

We also assumed that rope access staff face 10 micromorts of risk per mission (a 0.001% chance of death); 4 people avoiding this risk 4 times per year, each with a statistical life value of $8,704,644, yields an annual employee risk benefit of $1,393. We feel that the qualitative benefit is larger than this monetization would indicate; redundant safety features are employed in rope access, but not performing the activity is the safest course of action.

Mission staff reacted to the hypothetical "Decision Effectiveness" benefit in a surprising way, stating that better decisions can be made when experts can respond in real time. Video and data are flat, and do not allow the inspector to interact with the structure and adjust the inspection in response to his or her findings. Delamination is a particular concern, and can best be assessed through touch; previous testing of sensor-based delamination has not produced impressive results, and may require perfect conditions. For these reasons, decision effectiveness is shown as

a negative benefit. Otherwise, responses from mission staff to questions about qualitative benefits were largely neutral or as we expected, but the feedback we received provides valuable context.

Regarding risk to agency operations, SMEs agreed that agency operations would be materially impaired by a fatality. The structures themselves are also very important, and if we were to lose the bridge at Parker Dam, for example, we could pass water but employees and equipment could not get to the site. However, UAS doesn't materially improve the reliability of the structure, and few structures are good candidates for such an inspection. For example, the Davis Dam bridge must be inspected by hand (via a trolley with a crank), along with other fracture-critical bridges that are required to be inspected at arm's length pursuant to Federal law.

SMEs also report that inspection of bridges is not data intensive; Reclamation is generally not looking for fatal flaws, but for general O&M recommendations, and those findings are usually readily apparent. We generally don't get much feedback on those recommendations, or questions about our objectivity. Stakeholders usually ask how findings can be fixed, rather than disputing them.

Costs related to the UAS program, mission-specific operations, and the resulting data products were estimated by the study team and populated into the BCA Summary spreadsheet for comparison against estimated benefits. The investments in technology, training, and certifications to support the use of UAS for bridge inspections totaled $74,300 in Year 0, with additional fixed costs accruing in Years 1 through 5 to maintain the capabilities of the program. Mission-specific operations costs are variable, and are only incurred as the UAS is used. Considering those costs, the annual net benefits of using UAS for bridge inspections in Years 1 through 5 range from about $10,000 to over $26,000. The net present value of this stream of costs and benefits is $28,263 at a 3.125% discount rate, and $17,808 at a 7% discount rate. Considering the additional qualitative safety benefits identified by SMEs, UAS is a very attractive option for performing bridge inspections.

## Scenario 2: Inaccessible Features - Rock Fall Inspections

# Rockfall Mitigation

### Benefit-Cost Analysis Summary

| Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Avoided Costs | | | | | | |
| Staff time + overtime | $0 | $0 | $0 | $0 | $0 | $0 |
| Hazard pay | $0 | $0 | $0 | $0 | $0 | $0 |
| Lodging and M&IE costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Fuel costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Administrative costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Equipment operations & maintenance | $0 | $0 | $0 | $0 | $0 | $0 |
| Risk Reduction | | | | | | |
| Reduction in risk to employees | $0 | + | + | + | + | + |
| Reduction in risk of facility damage or failure | $0 | ++ | ++ | ++ | ++ | ++ |
| Environmental, Economic, and Social Benefits | | | | | | |
| Reduced carbon footprint (assuming electric UAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Efficient, effective, and transparent decisions | $0 | ++ | ++ | ++ | ++ | ++ |
| Facilitation of interagency relationships | $0 | + | + | + | + | + |
| Data Products | | | | | | |
| Collection of new data | $0 | ++ | ++ | ++ | ++ | ++ |
| Improved data quality | $0 | ++ | ++ | ++ | ++ | ++ |
| Improved data objectivity | $0 | ++ | ++ | ++ | ++ | ++ |
| Support of open and accessible data initiatives | $0 | $0 | $0 | $0 | $0 | $0 |
| Total Benefits by Year | $0++ | $0++ | $0++ | $0++ | $0++ | $0++ |

| Costs by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| UAS Program Costs | | | | | | |
| Airframe | $33,900 | $0 | $0 | $0 | $0 | $0 |
| Accessories | $4,200 | $0 | $0 | $0 | $0 | $0 |
| Sensors | $11,000 | $0 | $0 | $0 | $0 | $0 |
| Training | $3,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Licensing/certification | $1,000 | $500 | $500 | $500 | $500 | $500 |
| Mission-Specific Operations | | | | | | |
| Pilot and spotter staff time + overtime | $0 | $9,213 | $9,213 | $9,213 | $9,213 | $9,213 |
| Pilot lodging and M&IE costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Pilot fuel costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Maintenance | $0 | $500 | $500 | $500 | $500 | $500 |
| Replacement Parts | $0 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Pre-flight compliance (approvals) | $0 | $3,000 | $3,000 | $2,000 | $2,000 | $2,000 |
| Contracting (333, OAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Public involvement | $0 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 |
| Data Products | | | | | | |
| Specialized computer(s) | $8,000 | $0 | $0 | $8,000 | $0 | $0 |
| Software purchase, licensing, and updates | $5,000 | $2,000 | $2,000 | $5,000 | $2,000 | $2,000 |
| Training | $5,000 | $0 | $0 | $5,000 | $0 | $0 |
| Staff time for new data analyses | $5,000 | $3,000 | $3,000 | $3,000 | $3,000 | $3,000 |
| Total Costs by Year | $76,100 | $23,213 | $23,213 | $38,213 | $22,213 | $22,213 |

| Net Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Annual Net Benefits (Costs) | -$76,100 | -$23,213 | -$23,213 | -$38,213 | -$22,213 | -$22,213 |

| Evaluation Metrics | | |
|---|---|---|
| Net Present Value at a 3.125% Discount Rate | -$193,967 | + unquantified benefits |
| Net Present Value at a 7% Discount Rate | -$182,047 | + unquantified benefits |

Rock fall inspection SMEs did not view UAS as a substitute for the resources utilized in the current annual inspection process, so there are no benefits associated with avoided costs for this mission. Instead of replacing climbs or climbers, UAS is projected to fly with staff members as they traverse a slope; this would add a cost to the current process, but provide substantive qualitative benefits as well.

First, there is a possibility that UAS could assist climbers in navigating the slope. Even small loose rocks present a hazard for people and infrastructure beneath a rock face; UAS cannot dislodge them safely as a climber would do, but may help the climber target those areas of higher risk. Recent rockfalls have removed multiple transformers from service for days at a time, materially impacting Reclamation's ability to deliver power. Where implementation of a UAS program reduces the risk of rockfall by making inspections and mitigation more efficient, this is a significant benefit.

In addition to facilitating annual inspections, UAS would enable Reclamation to rapidly respond to rock falls by identifying the source of the rock using 3D data, and quickly inspecting that area to determine if or how much more rock is likely to fall. "Good data is what effective decisions are based on," SMEs report. Currently, joints in the rock faces around Hoover Dam can be measured from photos taken from across the canyon, but the level of detail is inadequate to identify all features; there are few good vantage points, and photos taken by climbers are too close up. For any necessary rock bolting, the geologist currently draws on printed photos to guide a contractor to the target area.

A prospective future benefit of UAS would be the enhancement of Reclamation's relationship with SRP through partnership in inspections at Horse Mesa Dam, which experiences active rockfalls but is partially inaccessible to climbers. Assisting our operating agent in improving slope stability management provides a benefit for our facility and could generate a cost share for the UAS program.

Costs related to the UAS program, mission-specific operations, and the resulting data products were estimated by the study team and populated into the BCA Summary spreadsheet for comparison against estimated benefits. The investments in technology, training, and certifications to support the use of UAS for rock fall inspections totaled $76,100 in Year 0, with additional fixed costs accruing in Years 1 through 5 to maintain the capabilities of the program. An investment cost unique to this mission is the purchase of at least 6 batteries, which enables the nearly continuous flight time envisioned by SMEs; optimal charging time per battery is 90 minutes, and a full charge delivers only 20-30 minutes of flight time.

Mission-specific operations costs are variable, and are only incurred as the UAS is used. The pilot and spotter are assumed to work the same hours as conventional mission staff. Considering those costs and our inability to monetize benefits for this mission, the annual net benefits of using UAS for rock fall inspections in Years 1 through 5 range from about -$38,000 to about -$22,000. The net present value of this stream of costs and benefits is -$193,967 at a 3.125% discount rate, and -$182,047 at a 7% discount rate, plus non-monetized benefits. Considering the

qualitative data benefits identified by SMEs, UAS may still be a desirable addition to our current rock fall inspection process; following an opportunity to try the technology, SMEs may wish to revisit how UAS is used in concert with conventional resources.

Scenario 3: Water Use Accounting - Orchard Surveys

# Orchard Surveys

## Benefit-Cost Analysis Summary

| Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Avoided Costs | | | | | | |
| Staff time + overtime | $0 | $0 | $0 | $0 | $0 | $0 |
| Hazard pay | $0 | $0 | $0 | $0 | $0 | $0 |
| Lodging and M&IE costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Fuel costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Administrative costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Equipment operations & maintenance | $0 | $0 | $0 | $0 | $0 | $0 |
| Risk Reduction | | | | | | |
| Reduction in risk to employees | $0 | + | + | + | + | + |
| Reduction in risk of facility damage or failure | $0 | $0 | $0 | $0 | $0 | $0 |
| Environmental, Economic, and Social Benefits | | | | | | |
| Reduced carbon footprint (assuming electric UAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Efficient, effective, and transparent decisions | $0 | + | + | + | + | + |
| Facilitation of interagency relationships | $0 | $0 | $0 | $0 | $0 | $0 |
| Data Products | | | | | | |
| Collection of new data | $0 | + | + | + | + | + |
| Improved data quality | $0 | + | + | + | + | + |
| Improved data objectivity | $0 | + | + | + | + | + |
| Support of open and accessible data initiatives | $0 | $0 | $0 | $0 | $0 | $0 |
| Total Benefits by Year | $0+ | $0+ | $0+ | $0+ | $0+ | $0+ |

| Costs by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| UAS Program Costs | | | | | | |
| Airframe | $41,900 | $0 | $0 | $0 | $0 | $0 |
| Accessories | $1,530 | $0 | $0 | $0 | $0 | $0 |
| Sensors | $11,000 | $0 | $0 | $0 | $0 | $0 |
| Training | $3,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Licensing/certification | $1,000 | $500 | $500 | $500 | $500 | $500 |
| Mission-Specific Operations | | | | | | |
| Pilot and spotter staff time | $0 | $6,207 | $6,207 | $6,207 | $6,207 | $6,207 |
| Pilot and spotter lodging and M&IE costs | $0 | $903 | $903 | $903 | $903 | $903 |
| Pilot and spotter fuel costs | $0 | $145 | $145 | $145 | $145 | $145 |
| Maintenance | $0 | $500 | $500 | $500 | $500 | $500 |
| Replacement Parts | $0 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Pre-flight compliance (approvals) | $0 | $3,000 | $3,000 | $2,000 | $2,000 | $2,000 |
| Contracting (333, OAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Public involvement | $0 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 |
| Data Products | | | | | | |
| Specialized computer(s) | $8,000 | $0 | $0 | $8,000 | $0 | $0 |
| Software purchase, licensing, and updates | $5,000 | $2,000 | $2,000 | $5,000 | $2,000 | $2,000 |
| Training | $5,000 | $0 | $0 | $5,000 | $0 | $0 |
| Staff time for new data analyses | $5,000 | $3,000 | $3,000 | $3,000 | $3,000 | $3,000 |
| Total Costs by Year | $81,430 | $21,255 | $21,255 | $36,255 | $20,255 | $20,255 |

| Net Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Annual Net Benefits (Costs) | -$81,430 | -$21,255 | -$21,255 | -$36,255 | -$20,255 | -$20,255 |

| Evaluation Metrics | | |
|---|---|---|
| Net Present Value at a 3.125% Discount Rate | -$190,361 | + unquantified benefits |
| Net Present Value at a 7% Discount Rate | -$179,348 | + unquantified benefits |

Orchard surveys are currently performed through an integrated process with other field verifications, which are conducted four times per year by a team of staff in vehicles, coinciding with seasonal cropping patterns. Orchard surveys were previously performed annually during a separate trip via helicopter, but are now performed primarily through remote sensing. Where imagery indicates a change or ambiguity in a permanent crop, staff attempt to perform a field verification during the first regularly scheduled trip. If attempts to view the extent of the field are defeated by a locked gate, staff will re-visit the field during each successive regularly scheduled trip until access to the field permits collection of the desired data. This may take all year; gates are eventually unlocked for harvest, or staff will enter on foot and perform a walking inspection of the field for up to an hour. Strong initial interest in UAS stemmed from the concept of field verification staff carrying UAS with them to deploy instantaneously, as needed, to survey any locked orchards. Research revealed that this concept is probably infeasible because field verification staff typically work alone, covering the survey area in five separate vehicles, and would require broad and unlimited authority to fly without notice over locations which cannot be predicted in advance.

Through discussions with SMEs, however, the following potentially viable UAS scenario was developed, which forms the basis for the UAS costs estimated for this mission. As part of their normal process, the primary field verification team would identify the orchards to be surveyed by UAS, planning an optimal route to those fields. A 2-person UAS team would be deployed shortly thereafter to the target fields, surveying them over an estimated 32 work hours at $96.98 per hour, driving the distance from Boulder City to Yuma to Indio and back. Fuel economy is assumed to be 15 miles/gallon, with gasoline costing $3/gallon. Travel expenses per person are assumed to include 3 nights of lodging at $91/night, 2 partial days of M&IE and 2 whole days at $51/day. This UAS mission would occur once annually, in concert with the first field verification trip; there would be no change to the existing process. Any avoided costs would arise through staff not needing to re-visit locked orchards later in the year, but those orchards are few and may be located near fields that would be visited anyway. The magnitude of distance and time savings is likely smaller and more variable than we can currently estimate, so the BCA Summary spreadsheet shows no avoided costs.

Other benefits of UAS for orchard surveys are expected to be moderate and non-monetary. Making the distinction between declining and growing orchards is difficult with imagery alone, and having a complete, timely, and objective data set improves the accuracy and precision of water use estimates in published reports. However, the impact of missing orchard data on those estimates is relatively small, being just a subset of a much larger picture. UAS could also provide a small safety benefit during the summer months by eliminating the cases where staff walk through orchards to collect data, risking exposure. If future UAS scenarios could reduce vehicle miles driven, an additional safety benefit would accrue; traveling 250 miles by car is assumed to increase the risk of death by 1 micromort (which may be an underestimate, given the mission-specific hazards of driving around canals, wildlife, and farm equipment).

Benefits related to interagency relationships and open data cannot be determined. There may be farmer, landowner, or district sensitivity to higher resolution inspection or monitoring, particularly if data could be made public. Reclamation would have to consider whether UAS flights might inadvertently gather personal information or proprietary production information. At the same time, progressive districts might value such data or footage, and this could only be determined on a case by case basis.

Costs related to the UAS program, mission-specific operations, and the resulting data products were estimated by the study team and populated into the BCA Summary spreadsheet for comparison against estimated benefits. The investments in technology, training, and certifications to support the use of UAS for orchard surveys totaled $81,430 in Year 0, with additional fixed costs accruing in Years 1 through 5 to maintain the capabilities of the program. Mission-specific operations costs are variable, and are only incurred as the UAS is used. Considering those costs, and our inability to monetize benefits for this mission, the annual net benefits of using UAS for orchard surveys in Years 1 through 5 range from about -$36,000 to about -$20,000. The net present value of this stream of costs and benefits is -$190,361 at a 3.125% discount rate, and -$179,348 at a 7% discount rate, plus non-monetized benefits. The future of UAS for orchard surveys would likely depend on inexpensive and readily available airframes and sensors, and a streamlined flight approval process including broad-scale landowner notification.

## Scenario 4: Environmental Management - Habitat Surveys

# Aquatic Surveys

### Benefit-Cost Analysis Summary

| Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Avoided Costs | | | | | | |
| Staff time + overtime | $0 | $0 | $0 | $0 | $0 | $0 |
| Hazard pay | $0 | $0 | $0 | $0 | $0 | $0 |
| Lodging and M&IE costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Fuel costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Administrative costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Equipment operations & maintenance | $0 | $0 | $0 | $0 | $0 | $0 |
| Risk Reduction | | | | | | |
| Reduction in risk to employees | $0 | $0 | $0 | $0 | $0 | $0 |
| Reduction in risk of facility damage or failure | $0 | $0 | $0 | $0 | $0 | $0 |
| Environmental, Economic, and Social Benefits | | | | | | |
| Reduced carbon footprint (assuming electric UAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Efficient, effective, and transparent decisions | $0 | + | + | + | + | + |
| Facilitation of interagency relationships | $0 | + | + | + | + | + |
| Data Products | | | | | | |
| Collection of new data | $0 | + | + | + | + | + |
| Improved data quality | $0 | + | + | + | + | + |
| Improved data objectivity | $0 | $0 | $0 | $0 | $0 | $0 |
| Support of open and accessible data initiatives | $0 | $0 | $0 | $0 | $0 | $0 |
| Total Benefits by Year | $0+ | $0+ | $0+ | $0+ | $0+ | $0+ |

| Costs by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| UAS Program Costs | | | | | | |
| Airframe | $41,900 | $0 | $0 | $0 | $0 | $0 |
| Accessories | $1,530 | $0 | $0 | $0 | $0 | $0 |
| Sensors | $11,000 | $0 | $0 | $0 | $0 | $0 |
| Training | $3,000 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Licensing/certification | $1,000 | $500 | $500 | $500 | $500 | $500 |
| Mission-Specific Operations | | | | | | |
| Pilot and spotter staff time | $0 | $27,930 | $27,930 | $27,930 | $27,930 | $27,930 |
| Pilot lodging and M&IE costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Pilot fuel costs | $0 | $0 | $0 | $0 | $0 | $0 |
| Maintenance | $0 | $500 | $500 | $500 | $500 | $500 |
| Replacement Parts | $0 | $2,000 | $2,000 | $2,000 | $2,000 | $2,000 |
| Pre-flight compliance (approvals) | $0 | $3,000 | $3,000 | $2,000 | $2,000 | $2,000 |
| Contracting (333, OAS) | $0 | $0 | $0 | $0 | $0 | $0 |
| Public involvement | $0 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 |
| Data Products | | | | | | |
| Specialized computer(s) | $0 | $0 | $0 | $0 | $0 | $0 |
| Software purchase, licensing, and updates | $0 | $0 | $0 | $0 | $0 | $0 |
| Training | $0 | $0 | $0 | $0 | $0 | $0 |
| Staff time for new data analyses | $0 | $0 | $0 | $0 | $0 | $0 |
| Total Costs by Year | $58,430 | $36,930 | $36,930 | $35,930 | $35,930 | $35,930 |

| Net Benefits by Year | Year 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Annual Net Benefits (Costs) | -$58,430 | -$36,930 | -$36,930 | -$35,930 | -$35,930 | -$35,930 |

| Evaluation Metrics | | |
|---|---|---|
| Net Present Value at a 3.125% Discount Rate | -$224,304 | + unquantified benefits |
| Net Present Value at a 7% Discount Rate | -$207,559 | + unquantified benefits |

Different types of habitat surveys are performed by Reclamation; this analysis targets aquatic surveys, which may be performed in a number of ways at various locations as described in Techniques for Monitoring Razorback Sucker in the Lower Colorado River, Hoover to Parker Dams, 2006-2007, Final Report. UAS is again poised to make substantial qualitative contributions to the mission, but SMEs are not able to estimate any costs of the current process that could be avoided through the use of UAS.

During the spawning season (January through April) semi-permanent remote sensor arrays are deployed at known spawning sites for the duration of the spawning event. PIT tag contact data are downloaded weekly without removing the sensors, and are used to make quantitative population estimates. To find a new spawning site, Google imagery and/or personal observation are currently used to identify desirable submerged and shoreline features such as alluvial fans and emergent vegetation. At areas of likely contact based on those features, a 4'x2' remote sensor can be deployed for up to 96 hours; if it produces data, then a net can be deployed at the site overnight to get fish in hand for further examination as desired. This is done on a monthly basis, year round, to qualitatively assess habitat selection by Razorback sucker throughout the year.

UAS would add to the existing process by collecting redundant data at known spawning sites, as a verification layer, and collecting video and still photos of nearby areas in search of new spawning sites. UAS would not replace any current activities, but could be flown nearby if conditions warrant while staff are already in an area of interest either deploying or retrieving sensors and/or data (presumably from a boat or the shore). The role of UAS in this scenario is to provide higher resolution imagery compared to Google, but quickly cover a wider area than a test sensor could, gathering data with an intermediate resolution which staff currently lack. From low-level aerial video, staff can assess fish density, distribution, movement and behavior that indicate species, spawning status, and other information, and can then focus on newly located spawning sites and intensify their data gathering pursuant to the usual process.

The moderate benefits described by SMEs reflect an elevated state of science that Reclamation could achieve with UAS. Over time, there have been slight dips in fish density at known spawning sites. Is it due to differences in imprinting for hatchery-raised fish, and where are these fish going, if not to the customary spawning sites? We may be seeing fewer large spawning aggregations, and more dispersed spawning sites, which directly impacts Reclamation's ability to gather larvae for rearing to size pursuant to its MSCP responsibilities. If UAS can be suitably flexible, staff can leverage existing site visits to learn a lot more about the species and respond quicker if our management techniques aren't having the desired effect.

The ability of UAS to add context to other types of data is a strength. Additionally, there is a public relations and educational aspect to the imagery that UAS could provide; visitor use at refuges and the public's perspective of the value of this science may influence the support we receive. These benefits must be weighed against the UAS program costs and mission-specific operations costs, which were estimated by the study team and populated into the BCA Summary

spreadsheet. The investments in technology, training, and certifications to support the use of UAS for aquatic surveys totaled $58,430 in Year 0, with additional fixed costs accruing in Years 1 through 5 to maintain the capabilities of the program. The sensors identified in the cost estimate exceed the capabilities (for video and still photos) requested by SMEs, but they are the only sensors available for the selected vehicle; they are also quite costly. A wider range of technologies available for purchase could improve the feasibility of UAS for missions such as this, where data needs are relatively low-intensity.

Mission-specific operations costs are variable, and are only incurred as the UAS is used. We assume, however, that the initial use of UAS for aquatic surveys would occur at Lake Mohave; it is a day trip from Boulder City, which requires no travel expenses, and would ideally enable staff to schedule flights during favorable weather. The pilot and spotter, both assumed to cost $96.98/hour for 16 hours per mission and 9 missions per year, consist of the majority of annual costs; in reality, UAS could accompany as many or as few missions as desired, and this may be an overestimate.

Considering those costs, and our inability to monetize benefits for this mission, the annual net benefits of using UAS for aquatic surveys in Years 1 through 5 are estimated at about -$36,000. The net present value of this stream of costs and benefits is -$224,304 at a 3.125% discount rate, and -$207,559 at a 7% discount rate, plus non-monetized benefits. Program staff should strongly consider sharing a UAS with another mission, to capture the above-described benefits at a reasonable cost.