# FEASIBILITY OF IMPROVING LOCAL DECISION MAKING IN ALASKAN COMMUNITIES WITH UNMANNED AIRCRAFT SYSTEMS AND ONLINE CLIMATE DATA TOOLS

Submitted to:
Native Village of Unalakleet Tribal Council

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# ACKNOWLEDGEMENT

## Land Acknowledgement

The primary focus of this project and the location of the Feasibility Study Project Manager are the traditional lands of the Inupiaq people in an area that is known today as Unalakleet, meaning "from the southern side" due to it being the furthest south Inupiaq community. In terms of the supporting Project Leads, the University of Alaska Fairbanks, Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) is located on the traditional lands of the Lower Tanana Dene people in an area that is now known as Fairbanks, Alaska. The Model Forest Policy Program's home base, Bonner County, Idaho, is located within the traditional lands of the Kalispel, speakers of a dialect of Interior Salish.

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# EXECUTIVE SUMMARY

## INTRODUCTION

In 2018, the Alaska Native Village of Unalakleet (NVU) received funding from the Bureau of Indian Affairs under its Program to Support Tribal Resilience and Ocean and Coastal Management and Planning. The project goal and objectives were to build local capacity to: (1) Address future climate related ocean and coastal management planning and challenges; and (2) Build long-term resilience through the establishment of a self-sustaining, localized and on-going data collection and analysis program. To that end, this Project analyzed the feasibility of establishing a regional data collection program utilizing an unmanned aircraft system (UAS) (drone and sensors) compared to other data collection systems.

To address the climate risks that the Alaska Native Village of Unalakleet and other Norton Sound Native Villages face, research was conducted under the following **nine scientific study areas**:

- Coastal erosion
- Flood preparation (river and sea)
- Infrastructure
- Water quality
- Plant community
- Cultural and historical sites
- Extractable materials
- Wildlife
- Air quality

The Project Team researched the following **five questions** to determine the feasibility of implementing a UAS program in rural Alaska:

- What are the costs to implement a community-managed, self-sustaining, UAS program?
- How could data collected from UAS and online climate tools contribute to long-term resiliency planning strategies?
- What are the short and long-term cost sharing/partnership opportunities for community managed data collection efforts?
- What are the resilience-related information needs of potential users (e.g. federal and state agencies, Norton Sound Villages, and regional entities) of LiDAR and/or other aerial system-collected data?
- How can we effectively share findings with Tribal Council members and other interested, appropriate parties to determine next steps and long-term project feasibility?

## METHODOLOGY OF STUDY COMPONENTS

The project research involved 6 different study components and methodologies:

- UAS Operational Solutions Matrix included research and synthetization of current commercial off the shelf small UAS payloads, aircraft, and post-processing software solutions available for the four of the nine scientific study areas; these four study areas reflected all of the relevant sensors and aircraft for the project excepting in situ samplers for air and water quality. Three information collection strategies were synthesized to create the matrix and to develop recommendations for local program implementation: a literature review of current small UAS (sUAS) used to collect quality data, a review of publicly available sUAS costs and specifications, and estimates from private companies.

- Online Tools Comparison Matrix included 3 steps: 1) Research existing tools comparison templates; 2) Research online tools that cover the nine scientific study areas; then 3) Populate the matrix. Besides background information on each site, a filtering system was developed that assessed applicability to study areas, geographic scope, date of collection, estimated time to review, and estimated bandwidth needs.
- Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis derived cost estimates using analogous estimating, where historical data for similar projects was used to estimate the cost of the planned project. Data was expressed in the same currency, standardized to the same scale (where possible), and inflation adjusted. Analogous costs and cost comparisons were calculated for drone monitoring versus traditional methods and by each of the nine study areas, looking at applicability and accuracy. Several assumptions guided the report.[1]
- Two Surveys were done. A simple 6-question survey was given at the February 2020 Alaska Forum on the Environment to gain a better understanding of attendee experience with UASs, their prioritization of the nine study areas and other concerns, and their interest in any follow-up. The second, longer survey, sent out in April 2020 to more than 300 people, built on the first survey. It asked questions to gain an understanding of a community's use of data in long-term planning and decision making, the type of data used and by whom, and where in Alaska the respondent lived.
- Integration and Applications of UAS and Online Climate Tools Data - Document Review. The Team selected a representative sample of planning documents and reviewed those plans to determine relevancy of UAS-collected and online tools data. It then entered that information into the Integration/Application of Data into Planning Matrix and wrote a brief summary of the findings.
- Partnership Options/Considerations. The Team researched types of agreements (general contract, service agreement, subscription, Memorandum of Understanding other) and then developed a partnership template.

**RESULTS**

The broader findings for key components are summarized here.

The team found that numerous small Unmanned Aircraft Systems (sUAS) exist which can support environmental decision-making. Sensors using a broad range of the electromagnetic spectrum are available for data collection and have been successfully miniaturized for sUAS flights. The data collected from these observational sensors can be georeferenced and subsequently processed to create high resolution orthorectified maps of an area. These data collection flights and orthorectified maps can be used as baseline data sets for monitoring change of different environmental conditions in a community or region.

[1] **Note:** For clarification, the costs identified in the UAS Operational Solutions Matrix identified start-up/initiation costs for monitoring the various study areas; those identified in the Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis identified operational costs and how they compare to manned and ground-based monitoring of the study areas.

With regards to the Online Tools Comparison Matrix, Alaskan communities have available an array of free environmental and climate tools developed by government agencies, science groups, universities, and other tribal organizations. Unfortunately, these web based tools are often a challenge to find, time consuming, complicated, data heavy, and it is not always clear whether a given tool is (a) relevant to the particular challenges faced by a community, (b) applicable to the specific geography of the community, and (c) usable by a community given other constraints.

In the Environmental Monitoring With Unmanned Aerial Vehicles: Cost Estimating & Analysis Overall Results study, the primary finding was that few details have been published related to costs. Given this scarcity of historical cost data, the number of study areas, and the variety of environmental contexts, scales, constraints, and variables that could be assessed with UAV systems, Cozzens determined that it was impractical to provide estimates with any measure of confidence. However, the estimates can serve as guideposts to help inform and strengthen decisions.

The section, Synthesized Results of the Nine (9) Scientific Study Areas, provides a deeper dive into the results for each of the scientific study areas by discussing individual findings for: 1) Unmanned Aircraft Systems; 2) Cost Estimating & Analysis for environmental monitoring; and 3) Online tools availability.

Under Additional Results, two additional categories were captured on the Online Tools Comparison Matrix - Permafrost and Collections of Tools as well as the summarization of Unalakleet Feasibility Study Project Survey (April 2020) results. For those who responded to the survey, infrastructure, water quality, wildlife and coastal erosion were of greatest concern. With regards to decision making, traditional ecological knowledge (TEK) followed by on-line data resources and tools were most used. Finally, two-thirds of respondents stated they lacked data for community decision making.

## DISCUSSION OF RESEARCH QUESTIONS

### Implementation Costs for a Community-Managed, Self-Sustaining, UAS Program

There are a number of costs that need to be included when considering whether or not to establish a local UAS monitoring program. Some costs are clear, like purchasing the UAS itself, supporting software, and the laptops to perform flight planning, data processing and archival routines. Other costs are less obvious, like the cost to train pilots for FAA certification, FAA testing, and the salaries of the individuals being trained. Once all costs are calculated, establishing a UAS-based monitoring program in rural communities is less expensive than performing regularly scheduled, contracted, manned aerial surveys over a community. To monitor localized impacts of climate change, documenting coastal erosion processes, prepare for flooding, perform search and rescue techniques and inspect infrastructure, on both a regular and ad hoc basis, then a UAS program is a cost effective solution.

Data Contribution to Long-Term Resiliency Planning Strategies

In terms of UAS data, the integration and application of such data into planning and decision making processes can be a valuable upgrade in quality and effectiveness at local, state, and federal levels. There are benefits to the quality and completeness of visual and scientific data available, improved collaborative process outcomes, and overall more effective risk assessment and adaptive strategy development. With regards to Online Tools, such tools can play a role in the decision making process. Whether a UAS program exists or not, such online tools could provide basic background (historical and/or projected) data/information that could be included in planning documents.

Short and Long-Term Cost Sharing/Partnership Opportunities

In the short-term, a Single-User or Multiple-User Program should first prioritize the nine scientific study areas and their related climate risks and then choose the top 2-3 study areas to focus on and from which to grow the UAS program. In the long-term, the next step would be to build upon the short-term UAS program, prioritizing the next set of study areas, baseline data to be collected and monitored needed over time.

Resilience-Related Information Needs of Potential Users

In order for data to be accepted by other users, protocols for data collection under the scientific study areas and emergency responses must be defined and agreed to by those collecting the data and those needing the data. Further, critical information needs include infrastructure motoring; collection of critical real-time data/information for immediate emergency or search and rescue mission; and extractable resources monitoring.

With approval of the Feasibility Study's release by the Native Village of Unalakleet Tribal Council, project findings will be shared more broadly with other communities and technical audiences through various virtual platforms. Further, discussions are taking place regarding making the Online Tools Comparison Matrix a living collection of tools, accessible to a greater number of people. Finally, steps are being taken towards long-term sustainability of a UAS program in Unalakleet and the Bering Strait region. The University of Alaska Fairbanks - Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) submitted a proposal, Remote Unmanned Aircraft System (UAS) Inspection and Response Team Development in the Bering Strait Region, that received funding in Fall 2020 from the Arctic Domain Awareness Center (ADAC).

**NEXT STEPS/RECOMMENDATIONS**

UAS and Cost Estimating / Analysis

In short, of the nine scientific study areas, UAS is only logical for examining some of their components, not all of them at this time. The most critical and easily achievable baseline data collection and ongoing monitoring with sUAS in rural Alaska can be accomplished with Electro-optical (EO), infrared and multispectral sensors. With minimal post-processing, these sensors can be used to monitor various aspects of all nine scientific study areas highlighted in this study, but are the least valuable for monitoring air quality. In addition, UAS can be an incredible asset during a Search and Rescue mission and/or assessment of a local emergency event. Hence, phasing in a UAS program based on a community's priorities can provide high value information at a reasonable cost.

In Barbara Cozzens' study, Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis, UAV monitoring and/or sampling indicated greater advantages than traditional methods for certain applications related to certain study areas (e.g. coastal erosion, flooding, infrastructure, water quality, vegetation between 10 and 20 hectares (ha)). Even for areas without a clear cost advantage though, UAVs proved to improve efficiency of monitoring or sampling, provide access to remote or inaccessible areas, and reduce risks to human health and safety, hence worth assessing whether the investment in UAV program meets a community's needs. Again such a program could be phased in and/or undertaken with another community or group of communities to help share the start-up and longer-term operational costs.

Online Climate Tools Matrix

Alaskan communities have available an array of free environmental and climate tools developed by government agencies, science groups, universities, and other tribal organizations. Unfortunately, these tools are often a challenge to find, time consuming, complicated, data heavy, and difficult to determine relevancy, applicability, and/or usability to a particular community. Online tools can though provide baseline information that could assist with long-term decision making.

UAS Data and/or Online Data Integration into Local, State, and Federal Plans and Reports

The integration and application of UAS data into planning and decision making processes can be a valuable upgrade in quality and effectiveness at local, state, and federal levels. With regards to the Native Village of Unalakleet (NVU) Project Tool Comparison Matrix or other online tools, such tools can play a role in the decision making process, either as a standalone resource or complementing a UAS program.

Research Limitations and Future Work

Adequate funding was a key limitation to researching all nine scientific study areas (start-up) operational solutions. An in-depth literature review was done by Dr. Garron for all study areas but a deep dive into identifying the technology and training needs and costs for high, medium, and low options was only done for the monitoring of four study areas (coastal erosion, flood preparation (river and sea), infrastructure, and water quality) considered at highest risk related to climate change.

In terms of limitations on cost comparison analysis, as noted by Barbara Cozzens in her study, there are dissimilarities between the study site and the policy site, the method used to transfer values, lack of consistency in reporting scales, errors in rescaling, and researcher reporting or calculating. Drone technology is changing rapidly, which should improve production efficiencies and costs. As the use of UASs increases, there will be an increase in cost data, the number of study areas, and the variety of environmental contexts, scales, constraints, and variables. In turn, the increase will provide updated cost estimates that have greater confidence.

Significance of Work

The research and findings contained in this document have significance and applicability beyond Unalakleet on several different levels especially related to: 1) The in-depth literature review and/or a comparison of cost estimates research completed by Garron and Cozzens; 2) The aggregation of the online tools matrix and the potential of transitioning it to an online system for use by Alaska communities and others; and 3) The analysis of using both UAS collected data and online data to complement Traditional Ecological Knowledge (TEK) in the decision making process.

# GLOSSARY

**2D** - Two-dimensional

**3D** - Three-dimensional

**AQI** - Air Quality Index

**BVLOS** - Beyond visual line of sight

**COTS** - Commercial off-the-shelf technology

**DOM** - Dissolved Organic Matter

**DSM** - Digital surface models

**EO** - Electro-optical sensor; RGB sensor; passive sensor

**FLIR** - Forward-looking infrared

**GPS** - Global positioning system

**LIDAR** - Light Detection and Ranging sensor; active sensor; uses pulses of light energy reflected off of a target to create a 3D map of surface characteristics

**NDVI** - Normalized Difference Vegetation Index; an indicator of plant community health and seasonal variability, through the relation of plant biomass to photosynthetic activity

**Photogrammetry** - Science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena.

**RGB** - Electro optical sensors operating in red, green and blue visible spectrum

**RS** - Remote-sensing; process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft)

**SAR sensor** - Synthetic aperture radar

**SfM** - Structure from Motion; a data processing methodology to create 3D maps from EO data.

**sUAS** - Small unmanned aircraft system, less than 55 lbs. gross take-off weight

**UAS** - Unmanned aircraft system; consists of aircraft, power source, payload, ground-controller station

**UAV** - Unmanned aircraft vehicle

**Utilidors** - Aboveground, insulated network of pipes and cables, used to convey water and electricity in communities situated in areas of permafrost.

**VTOL** - Vertical Take-Off and Landing; refers to a UAS that takes-off and lands vertically, but flies operationally horizontally

# 1. INTRODUCTION

## 1.1. BACKGROUND

### 1.1.1. PROJECT FUNDING & TIMELINE

Project funding came from the Bureau of Indian Affairs – Program to Support Tribal Resilience and Ocean and Coastal Management and Planning Grants Program FY 2018, Category 4. Ocean and Coastal Management Planning. The award was received in the fall of 2018 (Award #A19AP0003); project work started in January 2019, with project wrap up December 2020.

### 1.1.2. PROJECT TEAM

**PROJECT LEAD**

**John Henry, Deputy Director, Native Village of Unalakleet**
**BIA Native Village of Unalakleet Project Manager**

John Henry grew up in a coastal village south west of Unalakleet called Stebbins. Shortly after graduating from high school, he enrolled into the University of Alaska Fairbanks graduating with a BS in Electrical Engineering. For 9 years, John worked in the field. Afterwards, he moved to a community to be closer to his family. For over 6 years, John worked for the tribe of Unalakleet as IGAP Coordinator/NALEMP Project Manager, and Grants Management Specialist. John was recently appointed as Deputy Director for the Native Village of Unalakleet.

**Dr. Jessica Garron, Science Team Lead, Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) - University of Alaska Fairbanks (UAF)**
**BIA Project Technical Specialist**

Dr. Garron has been conducting applied research since 1996. As ACUASI's Science Team Lead, she identifies remote sensing and UAS technological solutions to scientific and operational problems. Most of Dr. Garron's years of field and biogeochemical laboratory experience have been spent performing research in interior Alaska, and on Alaska's Seward and Kenai Peninsulas. Dr. Garron recently earned her PhD from the University of Alaska Fairbanks with finalization of her dissertation titled, "Integration of Remote Sensing Technologies into Arctic Oil Spill Response." Garron is the technical lead on this project, and is the Principal Investigator for the follow-on project funded through the Arctic Domain Awareness Center, "Remote Unmanned Aircraft System (UAS) Inspection and Response Team Development in the Bering Strait Region."

**Margaret Hall, Model Forest Policy Program Associate Director**
**BIA Project Coordination Consultant**

Margaret Hall supports efforts to implement climate resilience solutions by rural and Indigenous organizations and communities. Since 2016, through the Model Forest Policy Program, she has worked with entities in the Norton Sound region to help implement local projects. She provides support in capacity building, project coordination, research and analysis of resilience issues and integration of findings into local plans and processes. Insight into rural communities comes from volunteering in her local community. Currently, she serves in her 2nd term as a school board trustee and is in 21st year on the local search and rescue team. Formerly, she served for 11 years on the county planning and zoning commission. She holds a Masters of Public Administration degree from the University of Washington with focus on Sustainable Community Development.

**PROJECT TEAM MEMBERS**

Over the course of the project and development of the Feasibility Study, the following individuals contributed in a number of different ways. Their assistance was critical and greatly appreciated.

- **Barbara Cozzens** (Principal, Science-Based Economics, Whistling Thorn Strategies) researched and wrote the Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis study that is a critical part of this Feasibility Study.
- **Dr. Nancy Gilliam** (Executive Director, Model Forest Policy Program) researched the online data tools that populate the Online Tools Matrix.
- **Dr. Gwen Griffith** (Program Director, Model Forest Policy Program) reviewed and analyzed key local, regional and federal planning documents and how UAS-sourced data can offer significant added value to planning and decision making for both public and private users.
- **Anne Jess** (Principal, The Doodle Biz) provided the visual synthesis of project components and the decision making process.
- **Alyx Perry** (Webinar Technical Specialist) provided IT support during the project's final webinar.
- **Hal Shepherd** (Principal, Water Policy Consulting, LLC) researched possible partnership options and considerations related to long-term sustainability of a UAS program.
- **Meghan "Sigvanna" Topkok** (Staff Attorney, Kawerak) provided additional research support related to partnership options and considerations.

### 1.1.3. NATIVE VILLAGE OF UNALAKLEET - THE STORY, DEFINING THE PROBLEM

#### The Story

The Native Village of Unalakleet is the initial focus of this Feasibility Study. With a population of approximately 700 people, the Alaskan Native community is located 148 miles southeast of Nome, 395 miles northwest of Anchorage, and sits on the coast of Norton Sound at the mouth of the Unalakleet River.

Unalakleet has a history of diverse cultures and trade activity. Archaeological finds date as far back as 200 B.C. to 300 A.D. On the upper river, nearby Athabaskans were considered "professional" traders with a monopoly on the Indian-Eskimo trade across the Kaltag Portage. Unalakleet was once a major trade center as the terminus for the Kaltag Portage, an important winter travel route connecting to the Yukon River. During the 1830's, the Russian-American

Company built a post in Unalakleet. In 1898, reindeer herders from Lapland were brought to Unalakleet, by Sheldon Jackson who was head of the Bureau of Indian Affairs, to establish sound herding practices. In 1901, the Army Signal Corps built over 605 miles of telegraph line from St. Michael to Unalakleet, over the portage to Kaltag and Fort Gibbon. The city was incorporated in 1974. The local economy is the most active in Norton Sound, along with a traditional Unaligmiut Eskimo subsistence lifestyle. Fish, seal, caribou, moose, and bear are utilized (NVU, 2021).

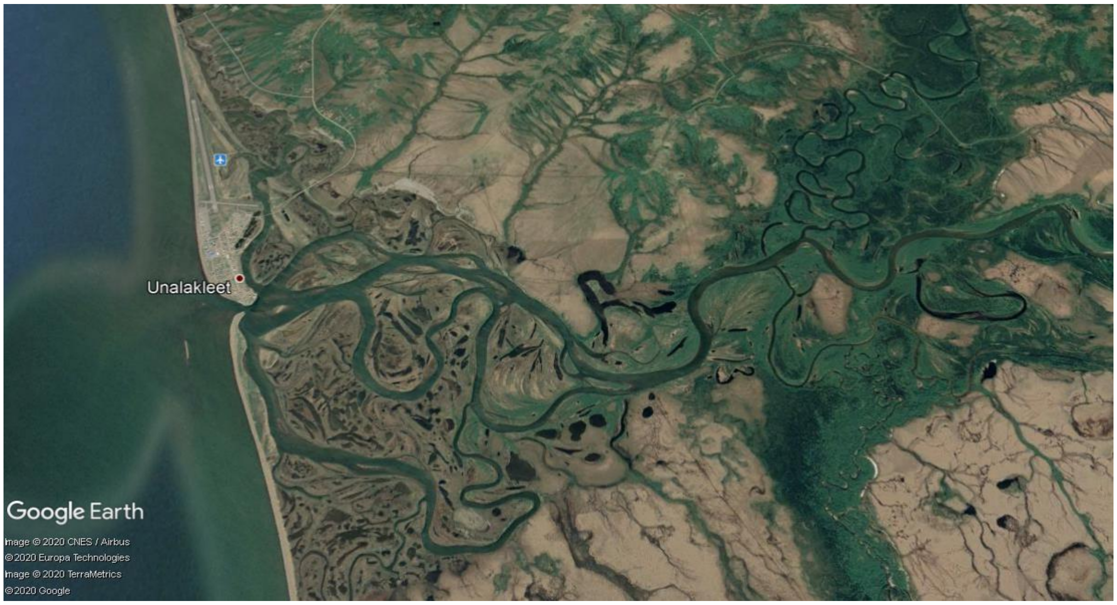



**Figure 1 - Map of Native Village of Unalakleet and Unalakleet River.**


**Figure 2 - Map of Alaska Norton Sound/Seward Peninsula Native Villages (Yellow Pins).**

## Defining the Problem

As coastal communities, the Native Village of Unalakleet (NVU) and other Norton Sound Alaska Native Villages are facing constant increasing risks to their ocean and coastal ecosystems and resources as a direct result of more extreme (weather) events and harmful environmental trends. Specifically related to Unalakleet, but not uncommon to others in the Norton Sound area, the following summarizes impacts currently being experienced by people, infrastructure, and natural systems:

- **Shoreline Erosion** - More intense fall storms are occurring with increased storm surge resulting in increased erosion. Unalakleet becomes an island when the river is high. There is a need to update studies on the rate of erosion.
- **River Flooding and Erosion of Hillsides** - Flooding of the Unalakleet River and erosion of hillsides are being seen on a more consistent basis.
- **Flooding - Melting Ice** - Floods are getting more frequent in the area. The first flood was in 1964, the last big one was 10 years ago. Current flooding is mostly caused by ocean storm surge.
- **Subsistence Impacts** - The Norton Sound area is experiencing increased changes to species population, habitat, ecology, hunting and gathering grounds including:
    - Unreliable ice for seal and walrus hunts, which creates dangerous hunting conditions. Rapid changes in ice flows take place sometimes in a few minutes to hours.
    - Changes to seal and walrus habitat patterns that send hunters further from home and/or further out on ice to hunt.
    - Salmon are moving north towards the Arctic Slope where they have not been seen before.
    - Changes to water temperature and river flows are taking place.
    - Cancers are being found in some fish and sea mammals. Changes in composition of fat being rendered; seal blubber turning black.
    - Increasing populations of jellyfish. Insect patterns are changing such as bees staying longer.
- **Water Source Risks** - Risks to Unalakleet's water sources are increasing. High water turbidity from erosion and loss of permafrost is being seen. Water shortages are experienced in the winter. Water pipes are aging/ rusted and more vulnerable to the fluctuation in temperature (freeze /thaw cycles). A location for water source (well) has been identified.
- **Tundra Wildfires** - Wildfires caused by lightning are creating air quality problems affecting people with allergies or lung disease. Air quality monitoring is needed to fully understand the extent of the problem.

Again, many of these impacts identified above are being experienced in one form or another by other Villages around the Norton Sound and throughout coastal Alaska and the interior.

### 1.1.4. FEASIBILITY PROJECT OVERVIEW

**Goal**

Build local and regional capacity to address the future ocean and coastal management planning and long-term resilience through the establishment of a self-sustaining, rigorous, localized and on-going data collection and analysis program.

**Objectives**

- Increase local/ regional capacity through greater understanding of current federal, state, regional (aerial), resilience-related data collection, potential gaps in/needs for aerial data and how such data contributes to long-term, strategic ocean and coastal management resiliency planning.
- Increase local/ regional capacity through greater understanding of potential partnership opportunities for critical, long-term data collection.
- Increase local/ regional capacity through greater understanding of funding options.
- Increase capacity of the Native Village of Unalakleet (and other Norton Sound/Seward Peninsula Native Villages) to address the future ocean and coastal management planning and long-term resilience through more rigorous, localized and on-going data collection and analysis.

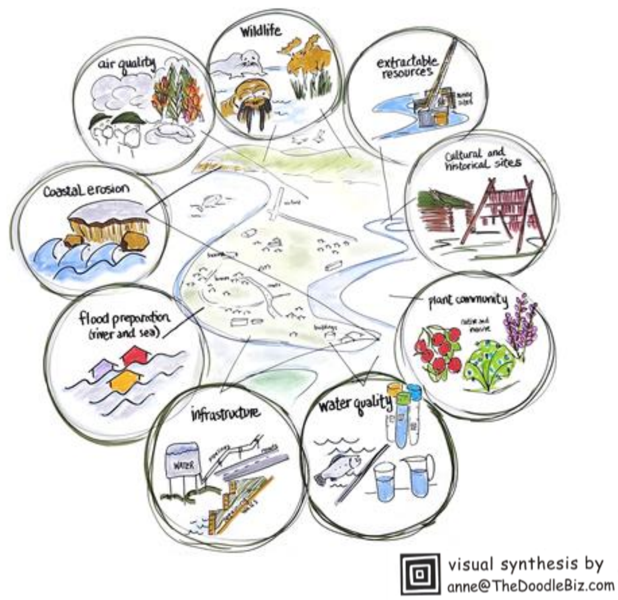
## 1.2. RESEARCH QUESTIONS ADDRESSED

The Project Team researched the following **five questions** to determine the feasibility of implementing a UAS program in rural Alaska:

- What are the costs to implement a community-managed, self-sustaining, UAS program?
- How could data collected from UAS and online climate tools contribute to long-term resiliency planning strategies?
- What are the short and long-term cost sharing/partnership opportunities for community managed data collection efforts?
- What are the resilience-related information needs of potential users (e.g. federal and state agencies, Norton Sound Villages, and regional entities) of LiDAR and/or other aerial system-collected data?
- How can we effectively share findings with Tribal Council members and other interested, appropriate parties to determine next steps and long-term project feasibility?

To address these questions, the Project Leads (Leads) identified nine scientific study areas being impacted by climate change in the Norton Sound region around which this study could be focused. The Project Team (Team) performed a literature review of the scientific areas, UAS operational considerations, and how UAS can be used for environmental monitoring and for the creation of decision-making support products. Members of the Team identified key contractual considerations for establishing a UAS-based monitoring program, whether independently, in partnership, or through contracting third-party vendors, and created a template for communities to modify in support of their data collection needs. To share the project findings, the Team presented this work to Alaskan community members in person and via an online webinar that was recorded and disseminated. Upon final review by the Native Village of Unalakleet Tribal Council, pending their permission, this Feasibility Study will be shared with webinar attendees and other interested parties directly and through various other means.

## 1.3. NINE SCIENTIFIC STUDY AREAS - OVERVIEW


To develop a matrix of sensors and aircraft that would be relevant and feasible for use by Norton Sound communities managing the impacts of climate change, nine scientific study areas of concern to the Native Village of Unalakleet] were defined and used as the science drivers for the technical solution investigation. The nine scientific study areas are identified below with their objectives (baseline and monitoring). These nine study areas were also used as the researching and analysis categories for the online tools, the cost estimating and analysis study, and developing the Professional Services Agreement template.

**COASTAL EROSION MONITORING**

***Objectives****: Identification and quantification of erosion-based coastal changes; identification and monitoring of erosion-prone coastal areas.*


- Baseline coastal profile; digital elevation models
- Identification of coastal deformation
- Traditional Ecological Knowledge (TEK) of coastline to target monitoring areas

## FLOOD PREPARATION (RIVER AND SEA)

***Objectives:*** *Identification of areas prone to flooding, new and old.*


- Digital elevation models of town
  - Quantify low-lying areas to avoid during development
  - Identify potential flood water channels
  - Identify changes overtime (annual differential analyses)
- Develop maps to support storm surge advisory warnings

## INFRASTRUCTURE MONITORING

***Objectives:*** *Identify current state of key NVU infrastructure.*


- Create baseline infrastructure maps (presence and status)
- Identify and map integrity anomalies of key the Native Village of Unalakleet infrastructure
  - Water delivery
  - Roads
  - Heat delivery

## WATER QUALITY MONITORING

***Objectives:*** *Measure the spectral characteristics of water and pollutants to determine quality.*


- Determine baseline conditions of sea water and freshwater sources
- Define regional water quality (e.g. fish habitat, potable, algal blooms)
- Determine seasonality of water quality parameters per waterbody
- Identifying and monitoring oil spills (surface area and trajectory input)

## AIR QUALITY MONITORING

***Objectives:*** *Monitoring air quality for human and animal health.*


- Monitor air quality index
  - Baseline values of stationary sources (municipal buildings as subset of region)
  - Measurements of known air quality disturbances (e.g. tundra fires, boats, mining equipment, oil spills, etc.)

**CULTURAL AND HISTORICAL SITE IDENTIFICATION AND MONITORING**

***Objectives:*** *Identification of structures and landscape anomalies that could be cultural resources; monitoring known cultural resources for change.*


- Identification of anomalous landscape features
  - e.g. square depressions on tundra
- Identify movement (uplift/sinking) of known historical structures
  - e.g. graveyards, chuches, etc.

**EXTRACTABLE RESOURCE IDENTIFICATION AND MONITORING**

***Objectives:*** *Map extractable resources and monitor extraction operations.*


- Gravel pit assessment (status and sustainability)
- Indicative geologic features for exploration (precious metals and stones, petroleum, etc.)

**WILDLIFE SURVEYS**

***Objectives:*** *Identify current populations and dynamics of wildlife species of concern.*


- Establish population baseline for key species
  - Land mammals (e.g. caribou, moose, fox, and beaver)
  - Sea birds (nesting, molting, migration)
  - Sea mammals (whales, seals, specific whale/seal species to region, migration)
- Monitor specific populations for behavioral, habit or numerical changes over time
- Develop co-management monitoring techniques using UAS

**PLANT COMMUNITY MONITORING**

***Objectives:*** *Identify current plant composition in NVU region and monitor changes in composition and habit.*


- Identify and map baseline plant communities in NVU region
- Identify changes to significant wildlife forage species (composition, habit, vitality, NDVI)

## 1.4. UNMANNED AIRCRAFT SYSTEMS IN CONTEXT

### 1.4.1. REMOTE-SENSING APPLICATIONS FOR INVENTORY AND MONITORING

Remote-sensing (RS) of the earth for natural resource inventory and monitoring has taken place consistently since the launch of the LANDSAT satellite mission in 1972 (Goward et al., 2001). These RS data sets range in resolution from the kilometer scale as observed from satellites, to the meter scale as observed with manned aerial missions from helicopters and planes, to the centimeter scale as observed by unmanned aircraft systems (UAS). UAS have the capacity to provide high resolution data sets in real-time in support of scientific and cultural observations (Madden et al., 2015; Marrero, 2019; Mishra & Rai, 2020; Papakonstantinou et al., 2019; Turner et al., 2016). These data sets can be combined with GPS information to create high resolution, georeferenced maps in either two or three dimensions, valuable for identifying specific resources and documenting change to those resources through time (Lazogiannis et al., 2019; Papakonstantinou et al., 2019; Westoby et al., 2012).

UAS can be outfitted with various payloads useful in supporting scientific inquiries and applied decision-making. Earth-observing payloads use different parts of the electromagnetic spectrum to remotely sense the earth's surface. The most mature of the data collection payloads for resource inventory and monitoring are the electro optical (EO) sensors operating in the red, green and blue (RGB) visible spectrum (Colomina & Molina, 2014; Manfreda et al., 2018; Mishra & Rai, 2020; Tmušić et al., 2020). EO sensors provide intuitive data frames like a photograph, and video streams. These data sets can be used to convey general information or situational awareness about an area, but also for detailed mapping efforts (Manfreda et al., 2018; Tmušić et al., 2020; Westoby et al., 2012).

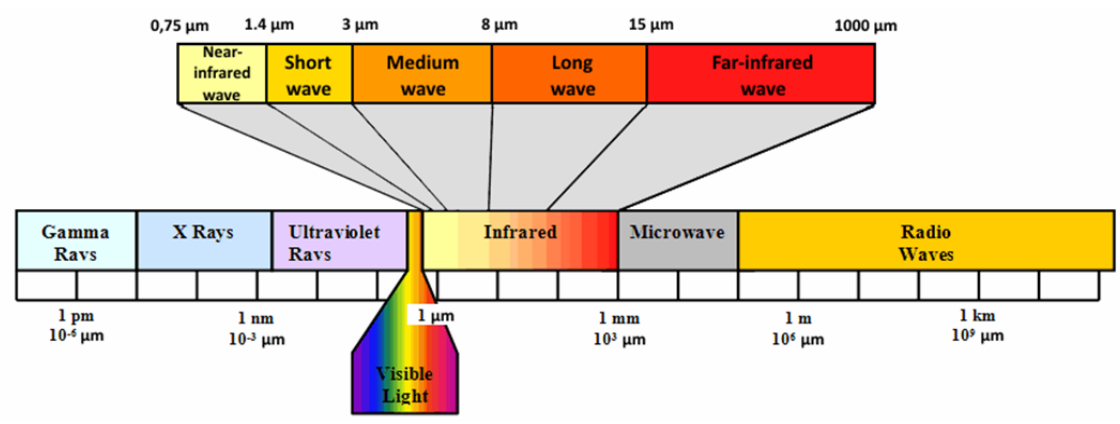



**Figure 3 – The electromagnetic spectrum; opranic.com**

**<u>Infrared sensors</u>** measure the portion of the electromagnetic spectrum between visible light and the microwave region (Figure 3). Longwave infrared sensors, also known as thermal infrared sensors, are the most ubiquitous of the infrared sensors, being used in many environmental surveys (Li et al., 2018; Linchant et al., 2015; Mader et al., 2016; Rakha & Gorodetsky, 2018; Shakhatreh et al., 2019) as well as search and rescue efforts (Dinh et al., 2019; Harada et al., 2020; Isser et al., 2020). TIR sensors identify differences in temperature of targets in contrast to the background environmental signals. These sensors are also often used in forest fire applications to identify hot spots when visibility is limited by smoke (Hua & Shao, 2017; Kabra & Singh, 2019; Yuan et al., 2017). Besides the RGB EO sensors, TIR sensors have been the most extensively miniaturized in support of UAS operations.

**Multispectral sensors** provide imagery from multiple ranges of the electromagnetic spectrum, most commonly from the blue, greed, red, near infrared, and shortwave infrared portions of the spectrum as depicted in Figure 3 (Berni et al., 2009; Colomina & Molina, 2014; Dufek et al., 2019; Gowravaram et al., 2018; Mader et al., 2016). These sensors collect imagery as discrete bands that can be fused into a unified data product, or kept discrete for discerning specific information. Multispectral sensors are very popular for vegetation studies as the multiple spectral bands allows for the calculation of Normalized Difference Vegetation Index (NDVI), a commonly used index for plant health and life stage that is calculated using NIR and Red bands of the electromagnetic spectrum (Beamish et al., 2020; Gowravaram et al., 2018; Shakhatreh et al., 2019). Multispectral sensors can also be used to detect oil spills (Alam & Sidike, 2012; Svejkovsky et al., 2012), inconsistencies in berms or levees (Dufek et al., 2019; Moorhead et al., 2012), infrastructure inspections (Mader et al., 2016; Shakhatreh et al., 2019) and examinations of water quality (Ross et al., 2019; Topp et al., 2020).

**Hyperspectral sensors** provide rich data sets that are challenging to process, analyze and store. Hyperspectral sensors are similar to multispectral sensors in that they are designed to collect spectral signals to within a certain range of the electromagnetic spectrum. However, the spectral signatures are collected across a range of the spectrum for each of the pixels within the sensor field of view resulting in voluminous data sets (Johnson et al., 2015; Murphy et al., 2017). The benefits of hyperspectral sensor can be realized for numerous applications and have been proven in the fields of agriculture (Adão et al., 2017; Hruska et al., 2012; Sankey et al., 2017; Zhong et al., 2018), oil spill detection (Andreoli et al., 2007; Liu et al., 2016), and water quality surveys (Mishra & Rai, 2020; Moorhead et al., 2012). Hyperspectral cameras are well-suited for plant species identification, and overall ecosystem valuations (Colomina & Molina, 2014; Johnson et al., 2015).

**Laser-based mapping systems** are energetically expensive and only recently effectively miniaturized for repeatable survey missions (Colomina & Molina, 2014; Sankey et al., 2017). Light detection and ranging (LIDAR) mapping techniques are popular surveying tools for determining fine-scale differences in elevations on the landscape that can be indicative of environmental changes or other obscured resources, such as an archeological site (Shakhatreh et al., 2019). LIDAR is also popular with ecosystem scientists that use the data to detail plant community structure both vertically and horizontally (Johnson et al., 2015) or for ascertaining hydrodynamic processes (Rhee et al., 2018). Many other usages exist for using LIDAR technology, but applications are tempered due to the complexity of data processing as well as the volume of data created by LIDAR target inspections (Colomina & Molina, 2014; Yin & Berger, 2017).

**Radar-based observations systems**, specifically synthetic aperture radar (SAR) systems, have been recently miniaturized for UAS operations. These sensors create large data sets like the hyperspectral and LIDAR sensors, but of the microwave portion of the electromagnetic spectrum, allowing for different types of analyses of the environment (Lort et al., 2018; Yan et al., 2018). SAR sensors are typically satellite-mounted and provide a synoptic perspective of environmental variables and how they interact with the microwave signals. The most common wavelengths used for SAR observations are X-band, S-band, C-band, L-band and P-band. Though radar can provide unique signatures of the environment for analyses, the energy and data storage requirements are large, and not well-suited to sUAS operations at this time.

The data collected by the above observational sensors will require some degree of post-processing to be usable by decision-makers. However, observational sensors are not the exclusive payloads for sUAS to support environmental observations. In situ samplers for air quality (Gao et al., 2016; Villa et al., 2016; Zhi et al., 2017) and water quality (Gholizadeh et al., 2016; Topp et al., 2020) also provide quality information for decision-makers. Unlike the spectral imagers, these sensors collect air or water samples directly and analyze the constituents of those samples either mid-flight or in a laboratory setting. These data sets are typically fused with other data sets used for mapping to create a data rich product for decision-makers. The type of data collected and the purpose of the UAS mission will determine the different post-processing methods and software packages available to create scenario specific data products.

### 1.4.2. DATA PRODUCTS AND POST-PROCESSING CONSIDERATIONS

Digital surface models (DSM) and orthorectified maps are the two most popular products generated from UAS-collected data (Doukari et al., 2019; Sankey et al., 2017; Seymour et al., 2018; Spencer et al., 2019). The two primary sensors used for DSM generation are LIDAR and EO sensors. Using post-processing techniques and supporting software packages, raw data collected from LIDAR or EO sensors is processed into a point-cloud to create a DSM. Once a DSM of an area of interest has been created, geospatial software packages can be used to create orthorectified (geometrically corrected) maps to identify or monitor environmental change of the area.

Structure from motion (SfM) is a popular processing and mapping technique used to make detailed orthorectified maps from georeferenced digital photographs to be used in change detection studies. Like LIDAR, SfM processing uses a point cloud-based methodology to create digital maps using remotely-sensed data from the visible spectrum. SfM is an easier and cheaper data post-processing solution for DSM and subsequent orthorectified map creation than LIDAR (Lazogiannis et al., 2019; Madden et al., 2015; Papakonstantinou et al., 2019; Westoby et al., 2012). SfM does not require ground control points for situating EO images in relative space, but instead relies on overlapping images of a target to develop orthorectified maps of an area

(Madden et al., 2015; Westoby et al., 2012). Agisoft Metashape (https://www.agisoft.com/) is a straightforward software program that can be used with data from different photogrammetric sensors (Aasen et al., 2015; Lazogiannis et al., 2019; Madden et al., 2015; Tmušić et al., 2020). Portions of the SfM processing pipeline can be automated within this software package, reducing the opportunity for “operator error” in data management to create data products for decision-makers.

### 1.4.3. TYPES OF UAS

There are a number of popular aircraft designs for small UAS (sUAS), some of which are easier to fly and collect data with than others. The three most common sUAS types are the multi-rotor vehicle, the fixed-wing vehicle and the vertical take-off and landing (VTOL) vehicles. Each of the types has benefits and drawbacks that need to be considered for efficient mission planning. Table 1 provides a simplified breakdown of pros and cons associated with the three aircraft types.

**Table 1 – Benefits and drawbacks of sUAS types for mission planning consideration.**

| sUAS Type | Benefits | Drawbacks | Mission Support |
|---|---|---|---|
| **Multi-rotor** | Capable of hovering; easy to launch and recover from small area; easy to fly; $ to $$$ | High-power consumption; typically short flight times; speed limited | Vertical inspections; tethered scenarios; following targets; |
| **Fixed-wing** | Longer flight times; can cover a large area; more stable; variable ease of launch and recovery; fast flight capacity | Typically flown at higher altitude (sensor resolution impacts); more challenging to fly than multi-rotor; cannot hover; $$$ | Large area surveys (km scale) |
| **VTOL** | Easy to launch and recover from small area; can cover a large area; | More challenging to fly than multi-rotor; hover not an option except during take-off/landing; $$$ | Large area surveys (km scale); ship-based operations |

Mission requirements need to be paired with available aircraft and sensor payloads in order to achieve the desired flight outcome. For example, Land-mapping missions benefit from longer endurance aircraft that can cover larger areas without the need for refueling or battery recharge. High resolution mapping (photogrammetric) missions need to be flown with overlapping flight swaths to account for data gaps and inconsistencies of flight due to wind and other factors (Aasen et al., 2015; Lazogiannis et al., 2019; Madden et al., 2015; Tmušić et al., 2020). Part of these considerations includes the maturity of the UAS-available sensors. For example, digital cameras operating in the visible spectrum have been well miniaturized as payloads for sUAS whereas hyperspectral cameras have not due to their complexity (Colomina & Molina, 2014; Johnson et al., 2015; Madden et al., 2015; Marrero, 2019).

### 1.4.4. PLACE-BASED CHALLENGES OF ARCTIC AND SUB-ARCTIC UAS OPERATIONS

The flexibility afforded by using sUAS for surveying and monitoring applications is somewhat counter balanced by the influence of environmental conditions on UAS operations. Small UAS by definition weigh less than 55 lbs. (Code of Federal Regulations, 2016) and are all subject to the effects of wind, precipitation and other weather-based phenomena. The fixed-wing style sUAS is the most developed due to its similarities to manned aircraft, and thus are more resistant to wind and precipitation, but the use cases for a fixed-wing UAS are more limited than a multi-rotor or VTOL UAS. The impacts of weather on sUAS are exacerbated in Arctic and sub-Arctic environments. Challenges of flying UAS in the Arctic include the environment, the robustness of the aircraft, and the lack of communication infrastructure (Du et al., 2019; Kramar & Määttä, 2018).

Temperature is one of the largest environmental variables impacting UAS operations in cold climates. Temperature can reduce the efficiency of mechanical and electronic UAS components and may also impact sensors payloads and the subsequent collected data. Most commercial off-the-shelf sUAS are rated to operate from -10° C to 40° C (22°F to 104° F) (Doukari et al., 2019; Du et al., 2019; Lapeña-Rey et al., 2017) with a few rated down to -20 C (-4° F) (Kramar & Määttä, 2018). Batteries are a common limiting factor at cold temperatures, as flight times are reduced when batteries become cold soaked. Some UAS use “smart batteries” that do not allow the sUAS to fly outside of the defined temperature range of the battery as defined by the manufacturer. Temperature combined with the humidity of the flight area will determine whether in-flight icing is a potential hazard. Icing of UAS components in-flight changes the weight balance of UAS and can result in a loss of performance and control (Armanini et al., 2016; Hann et al., 2017; Liu et al., 2019). As the effects of in-flight icing change are aircraft dependent, understanding the components of icing (drag and trim) that can impact a range of aircraft types is important for mission planning in cold regions (Armanini et al., 2016; Rakha & Gorodetsky, 2018). Wind reduces battery lifespan as the UAS uses more energy to maintain course, sUAS operations are limited by line-of-sight operations which can be easily impaired by fog, and precipitation as either rain or snow can easily damage exposed electronics. Though some solutions exist for weatherizing aircraft and increasing the operational temperature range of UAS, the need for more operational solutions for cold climate UAS flight is needed. These environmental factors also impact the UAS pilots and observers operating these aircraft. Health and human safety is paramount to every UAS mission, and if environmental factors are impacting the mechanics of UAS operations, they are likely impacting the human operators as well.

Cybersecurity concerns impact sUAS compatibility with various missions. For example, U.S. federal agencies do not want to use data collected with drones made in China due to known transmission of metadata and unknown transmission of other in-flight collected data, nor are federal agencies allowed to purchase sUAS manufactured in China (USDOI, 2020). Cybersecurity of sUAS flights in remote Alaska are minimal due to the lack of communication infrastructure for information transmission. Communication infrastructure challenges at high latitudes are based on the lack of populace and thus a lack of investment in infrastructure. Cellular towers provide localized service, but are not uniformly distributed which prevents the use of these networks for data delivery beyond the local community. Similarly, without roads and railways extending from city centers to remote communities, utility corridors do not exist for installation of communication systems. Most UAS are controlled by line-of-sight radio communications using the frequencies 2.4 GHz and 5.6 GHZ, accessed over localized WiFi networks broadcast from the ground control station (Colomina & Molina, 2014; Murphy et al., 2017). These signals can be obscured by landscape features, atmospheric conditions and other frequency interferences, and are typically limited to a range up to 2 miles. Satellite-based communications are employed for long-range UAS that are flying missions beyond visual line of sight (BVLOS) (Besada et al., 2018; Seymour et al., 2018), for both control of the vehicle as well as data transfer as available. Reliance on satellite-based communications sUAS operation and data delivery is not routine for missions operated within line-of-sight.

## 1.5. UNMANNED AIRCRAFT SYSTEMS AND THE NINE SCIENTIFIC STUDY AREAS

Following is the literature review conducted by Dr. Jessica Garron for the nine scientific study areas, which were used as the science drivers for the technical solution investigation. The scientific study areas are: Coastal erosion monitoring; Flood preparation (river and sea); Infrastructure monitoring; Water quality monitoring; Air quality monitoring; Cultural and historical site identification and monitoring; Extractable resource identification and monitoring; Wildlife surveys; and Plant community monitoring.

### 1.5.1. COASTAL EROSION MONITORING

Alaskan coastal communities are increasingly impacted by large winter storms due to inconsistencies in regional sea ice cover (Clement et al., 2013; Eicken et al., 2016; Janzen et al., 2019). These storms are increasing erosion rates along Alaska's coastline, putting communities at risk for loss of assets into the sea. Summer storms are also having a larger impact than previously observed due to the thawing of regional permafrost, resulting in large pieces of unfrozen ground falling into the ocean (Beamish et al., 2020; Nicu et al., 2020; Payne et al., 2018). To identify and quantify these erosion-based coastal changes, and areas of coastline that are particularly prone to erosion, UAS outfitted with various observational sensors can be used to collect data in support of short and long-term coastal monitoring efforts.

Coastal surveys require the development of a baseline coastal profile that can be manually generated or calculated by creating digital elevation models of the current coastline. These baseline profiles serve as a time zero measurement for future changes, with calculations based off of the wet/dry waterline (Marrero, 2019). However, the high winds, moisture and variability of the coastline itself can make coastal surveys with sUAS challenging (Doukari et al., 2019). To be able to perform the sUAS data collection flights, flight protocols need to take into account these environmental variables to be able to collect the quality data sets required for change detection analyses.

UAS outfitted with EO sensors have been used to calculate the amount of erosion that has taken place, but also identify areas at risk of higher erosional rates (Doukari et al., 2019; Marrero, 2019). By delineating an inland baseline and performing repeated UAS missions to include the coastline, baseline and area in between, coastal changes in meters per year can be calculated (Doukari et al., 2019; Lazogiannis et al., 2019; Marrero, 2019; Turner et al., 2016). Seymour et al. (2018) found that orthorectified maps created by SfM processing were comparable when using either EO combined with quality GPS data or laser scans of the coastline from a ground-based LIDAR system. This result allows for significant cost savings as the photogrammetry grade EO sensors and sUAS systems are far less expensive than either ground-based or UAS-based LIDAR survey systems, but also provide products with low uncertainty (Lazogiannis et al., 2019; Papakonstantinou et al., 2019; Seymour et al., 2018).

### 1.5.2. FLOOD PREPARATION (RIVER AND SEA)

Air temperature, snow depth, rainfall and glacial activity all contribute to water volumes and flow in Alaskan rivers and along its coastline. Climate change influences on these parameters may cause increased flooding, that can in turn impact subsistence hunting and community infrastructure security. Most rivers in the Arctic and sub-Arctic freeze over during the winter. In the spring when these rivers thaw, 50% of annual river discharge takes place during breakup (Arnborg et al., 1966). Flooding during breakup has been identified as one of the greatest impacts to erosion rates along rivers, and is heavily influenced by increased snowfall and faster snowmelt during break up resulting from climate change (Bieniek et al., 2011; Kontar et al., 2015; Payne et al., 2018). Flooding can also be experienced in coastal communities during large storms when sea ice is not present to protect the coastline from erosion and storm surges (Lazogiannis et al., 2019; Seymour et al., 2018). Being able to monitor the conditions that can lead to flooding events as well as the impacts of those events when they occur is important for community decision-making that will influence community livelihoods in the short and long-term.

Remote sensing tools have been successfully used to monitor open water and ice conditions, including break-up and large-scale flooding events in river and coastal locations. Using multispectral, radar, infrared, and optical payloads, satellite mounted sensors have been successful in monitoring large river systems, but are limited in the value they provide for monitoring smaller rivers and coastal changes on the meter scale as opposed to the kilometer scale (Alfredsen et al., 2018; Kontar et al., 2015; Li et al., 2018; Payne et al., 2018). Using the same types of sensors, UAS are ideal for surveying and reporting on conditions that could lead to localized flooding or for observing active flood conditions at the meter scale.

Many studies have highlighted the importance of using UAS to create detailed 3D maps of riverbanks and coastlines with LIDAR and EO sensors (Fonstad et al., 2013; Kontar et al., 2015; Moorhead et al., 2012; Westoby et al., 2012). These maps are important for change detection analyses, but also for flood forecasting based upon elevation and baseline information to support decision-making. UAS have also been used to understand river location evolution, especially in delta regions, and in support of developing community sustainability practices (Lazogiannis et al., 2019; Moorhead et al., 2012). Researchers have used UAS with different payloads to monitor the streamflow of rivers (Manfreda et al., 2018; Moorhead et al., 2012) with the potential for flooding due to high water conditions (Alfredsen et al., 2018; Tmušić et al., 2020), ice jams during spring break up, and during active flooding events (Alfredsen et al., 2018; Feng et al., 2015; Kontar et al., 2015). The information UAS can provide to support decision-making about flood prevention and response is demonstrated, but the development of a consistent UAS monitoring program for flood prevention and response has yet to be established in Alaska.

### 1.5.3. INFRASTRUCTURE MONITORING

Roads, bridges, utilidors, bulk fuel facilities, pipelines, water treatment plants, electrical generation and transmission stations, power lines are all examples of infrastructure assets that require monitoring for integrity. As with all sUAS data collection flights, Infrastructure monitoring requires the integration of stakeholder expertise in order to design and conduct quality inspection missions (Besada et al., 2018). Owners and operators of infrastructural components are looking for specific information to understand if their assets are in working order or if they are in need of repair, whereas UAS pilots are looking for safe flight parameters and need guidance on which components of the inspection require greater monitoring detail. The inspection target will also indicate what UAS type is best for the operation. Fixed-wing UAS are better suited for surveying linear infrastructure such as roads, pipelines, power lines, whereas multi-rotor vehicles are better for inspecting infrastructure with vertical components, such as power generation plants, and refining facilities. Once the data has been collected, the creation of useful data products will also vary based upon the information needs of the infrastructure manager. For example, video collected for review along the length of a pipeline will have far less utility for a pipeline manager than having point indicators of breached in that pipeline on a static map. Developing consistent monitoring protocols with consistent data products are requirements for developing a long-term, successful monitoring program.

Inspections could be observational, or inspections can include the collection of gas and water samples (Besada et al., 2018). Thermal signatures from transmission infrastructure can be used to determine integrity breeches or inefficiencies based upon aging infrastructure, but also determine integrity of buildings and insulation efficiencies (Rakha & Gorodetsky, 2018; Yao et al., 2019). Building inspection techniques using multispectral sensors are becoming more popular as the different spectral bands reveal specific characteristics of construction integrity (Mader et al., 2016).

Algorithm development for change detection is a developing technique popular for infrastructure inspection targets. Many of the algorithms originally designed for environmental analyses are well suited for automated infrastructure monitoring, but caution needs to be exercised throughout the development of these techniques as human perceptions about severity are challenging components to integrate into automated processing routines (Spencer et al., 2019). Another cutting edge application of UAS for infrastructure inspection involves flying UAS BVLOS to perform surveys beyond line of sight of the human eye. Safe BVLOS flights increase the efficiency for monitoring of extensive linear assets, like railroads, highways and pipelines. However, BVLOS flights are just now emerging as part of the FAA regulatory framework for UAS, and require significant flight supporting resources, especially in the area of collision avoidance, to be approved by the FAA (Shakhatreh et al., 2019).

### 1.5.4. WATER QUALITY MONITORING

Localized water quality can directly impact human health while simultaneously influencing long-term impacts on an ecosystem. Water quality can be measured directly via sample collection, or remotely using a variety of techniques. Common indicators of water quality are often based on color and turbidity, which can be described as the reflectance or absorption of the signal in the RGB portion of the electromagnetic spectrum. Chlorophyll-A which is representatives of phytoplankton abundance, Dissolved Organic Matter (DOM) from detritus or run-off, and total suspended solids from inorganic or organic sources are three common measurements used as indicators of water quality (Blix et al., 2018; Gholizadeh et al., 2016). By monitoring these three parameters, water quality seasonality as well as acute changes can be documented.

UAS can be used to carry the sensors for water quality analyses, and are able to fly close to the water to obtain high quality electromagnetic signatures. EO sensors measuring RGB light are well developed and easily accessible for studies measuring chlorophyll-A, DOM and suspended solids in water. Thermal infrared sensors have also been used for monitoring water quality as temperature is an indicator of quality and stress (Johnson et al., 2015; Madden et al., 2015). Hyperspectral remote-sensing is especially valuable for detailed water quality analyses (El-magd et al., 2014; Topp et al., 2020) but multispectral data can also provide quality information that is easier to process while also providing a more synoptic view of water quality or water contaminants (Garcia-Pineda et al., 2020; Murphy et al., 2017; Svejkovsky et al., 2012). Multispectral sensors have been successfully miniaturized with well-developed post-processing routines and can provide data from both RGB and infrared portions of the electromagnetic spectrum simultaneously. Water quality can be assessed with the aid of sUAS for direct sampling. In 2020, Garcia-Pineda demonstrated a sUAS carrying a water trap that could be deployed to collect water samples to help determine oil spill thickness to support quality tactical decision-making during an oil spill response (Garcia-Pineda et al., 2020).

### 1.5.5. AIR QUALITY MONITORING

The primary contributions to poor air quality across Alaska come from forest fires, volcanos, and fossil fuel emissions from either naturally occurring or anthropogenic sources. Smoke from forest fires and ash from volcanos can obscure visibility hundreds of miles away and also negatively impact the air Alaskans breathe. Harmful components of forest fire smoke and volcano ash include the chemicals released upon ignition/eruption and the smoke/ash particles themselves that can be lodged into lungs during regular exertion. Exhaust fumes from the combustion of heating fuels, and gas plumes resulting from accidental release of chemicals into the environment can also be detrimental to human health and are harder to visually detect than smoke or ash. Being able to measure in situ air quality is very important during a hazardous materials release and the subsequent response action. For example, during an oil spill response, responders need to be able to identify and isolate the “hot zone” where chemical concentrations in the air are hazardous, and where specific personal protective equipment is required for safe operations.

To quantify these airborne pollutants, the Air Quality Index (AQI) is used. AQI is a descriptor of the concentration of particles in the air that are categorized as $PM_{10}$ (particle size of 10 micrometers or less) or $PM_{2.5}$ (particle size of 2.5 micrometers or less) and the chemical components in the air, collectively called aerosols. Typical air quality measurements are collected from stationary passive or pump-assisted samplers or samplers that are mounted to a vehicle to collect air samples over an area. Most samplers are designed to collect either particle size ($PM_{10-2.5}$) and particle density (Leith et al., 2007) or chemical constituents in the air, like nitrous oxides, sulfur oxides, and other hazardous molecules (Zhi et al., 2017). Optical particle counters use spectrometers calibrated to various wavelengths can also be used to measure the size of particles in the air by the way the light is scattered in the sample (Gao et al., 2020). Some of these samplers work through the diffusion of air on to a microscope slide that is subsequently analyzed for the collected components.

Satellite and manned aircraft based sensors for measuring spectral characteristics of aerosols do not have the required spatial and temporal resolution to be valuable for localized air quality monitoring and decision-making (Villa et al., 2016). Alternatively, UAS can provide higher resolution quantification of these airborne contaminants while reducing the risk of human exposure. UAS can fly through plumes of gas or smoke with minimum impact to the aircraft or sensor payload to support localized monitoring and air quality management decision-making. Similar to other monitoring efforts, UAS can provide in situ measurements of air quality both vertically and horizontally.

Measuring air quality using UAS typically involves the collection of small particles comprising smoke, or gas detectors calibrated to the chemical constituents of the smoke. Particle samplers can be mounted to a UAS to collect targeted samples, but the capacity for multiple sample collections in one flight is limited, impacts of wind and drafting from the UAS itself significant, and the geographic variability is high. There are several alternative payloads that can be used on UAS to support air quality monitoring. Traditional EO payloads have been used in conjunction with ground-based stationary air quality sensors to develop a haze index that can be monitored with UAS, and that also support vertical profiling of the air (Gao et al., 2020; Yi Liu et al., 2020). This methodology also supports AQI observation over a larger area than what is typically represented using the stationary samplers. An additional benefit of using optical-based sensors to measure AQI is the reduced energy consumption of the payload as compared to particle and gas samplers that employ air pumps and either physical samplers or calibrated spectral cameras (Gao et al., 2020; Yi Liu et al., 2020). LIDAR has been used to measure particle size (Villa et al., 2016), but requires extensive post-processing know how beyond mapping. At this time, there are not many reliable sensors designed to collect quality AQI information from sUAS (Villa et al., 2016).

Real-time information can be streamed from air samplers if localized communication networks exist to support those relays. Samplers mounted to UAS need to have a WiFi component to be able to relay AQI data in real-time (Zhi et al., 2017). To date, no air sampling sensors have been commercially integrated into a UAS, therefore, the samplers themselves need to have the communication capacity to relay AQI data.

Each of these payload components (sampler sensor, pumps, communication network) add weight to the aircraft, which in turn reduces flight times for sUAS. Particle samplers are heavy so best suited for fixed-wing, but fixed-wing are not best suited for localized measurements the way multi-rotors are. To accurately collect air samples, UAS need to be able to fly slow to collect realistically place-based samples, followed by extensive post-processing to calculate the effects of temperature, humidity, wind and UAS-derived turbulence on the sample (Emran et al., 2017; Gómez & Green, 2017; Reuder et al., 2012).

### 1.5.6. CULTURAL AND HISTORICAL SITE IDENTIFICATION AND MONITORING

Coastal Alaska is rich with cultural resources of the past and present, both discovered and unknown. These valuable resources can be located anywhere on the landscape and often are near transportation corridors of rivers or coastlines. These assets and the sacred lands of which they are a part of, are at risk when there are changes to these coastlines. Coastline changes can be due to erosion, new settlements, and infrastructure to support communities along the coasts, all of which can be archived and monitored using UAS. UAS can be used to both identify and monitor natural threats to cultural resources (Doukari rt al., 2019; Madden et al., 2015; Papakonstantinou et al., 2019), and provide the maneuverability and spatial resolution needed to collect the nuanced details of most cultural resource sites.

Numerous remote sensing tools have been demonstrated to support the identification and monitoring of archeological and other cultural resources, the choice of which depends on cost and complexity. UAS outfitted with EO cameras offer a straightforward imaging solution to help to identify cultural resources on the landscape, and in some cases, somewhat submerged in the ocean. Papakonstantinou and others were able to use UAS carrying an EO payload to identify partially submerged ancient harbors and critical archeological details in relatively clear Mediterranean waters, even when flown at 100 m above the sea surface. In the same study, they were able to also determine the current state of those cultural resources, a method that was also employed in determining the integrity of historical buildings at higher resolutions than available from airplane or satellite-based optical imagery (Madden et al., 2015; Papakonstantinou et al., 2019). EO cameras mounted on a UAS can also be used to support orthomosaic and 3D map creation through SfM processing, allowing for the identification and precise placement of features that would otherwise be obscured by vegetation or perspective (Johnson et al., 2015; Madden et al., 2015; Marrero, 2019). The automated routines developed for various SfM processing software also reduces the amount of time spent learning the processing techniques, and more time analyzing the resource data. Imagery collected by UAS-mounted EO sensors has also been fused with traditionally collected aerial photography that had been digitized to create a database of change over time. In this study, UAS images were integrated into the GIS using Drone2Map, where images were then fused within the ArcGIS environment, allowing for the application of the Digital Shoreline Analysis System (DSAS) tool typically used in coastal erosion surveys, to determine not only the precise location of archeological sites, but also to determine the level of risk to erosion of the sites (Marrero, 2019).

LIDAR has been established as a powerful tool for the identification of landscape and historical features that have been partially submerged or otherwise obscured by soil or vegetation. By analyzing the digital elevation models produced from the LIDAR point-cloud, small landscape inconsistencies that indicate an archeological asset become clear (Devereux et al., 2008). These data also reveal unique shapes and distribution patterns of burial sites and previously existing structures (Adamopoulos & Rinaudo, 2020; VanValkenburgh et al., 2020).

Infrared, multispectral and hyperspectral sensors reveal the unique electromagnetic signatures of the cultural materials as compared to the background environment (Johnson et al., 2015; Pignatti et al., 2017; Savage et al., 2012). Using multispectral data to produce NDVI maps over known or suspected archeological targets allows researchers to discern the “unlike” features of the landscape through spectral signatures and impacts of those features on the vegetation growing on them (Agudo et al., 2018; Calleja et al., 2018). This technique has been demonstrated successfully in Arctic environments, where vegetation changes are dramatic and seasonally short-lived (Fenger-Nielsen et al., 2019). The thermal signatures between artifacts and the surrounding environment are depending on the excitation of the signal, or the "heat" of the target. Unless the pre-historical/historical target is composed of different materials than the surrounding landscape, it will not likely have a distinct thermal signature. For example, a quarried foundation for a structure will have a different thermal signature than the surrounding vegetation. Recognizing the unique capacity of each type of remote sensors miniaturized for UAS to support cultural resource inquiries allows for researchers and enthusiasts to identify mapping solutions for these resources based on their comfort level with processing tools and technical costs.

### 1.5.7. EXTRACTABLE RESOURCE IDENTIFICATION AND MONITORING

Resource exploration is the identification of a mineral formation target that is indicative of a given natural resource. Once a target has been identified, volume calculations, geologic surveys, topographic surveys, and 3D surface models of these target formations are created using remote sensing tools. EO, infrared, multispectral, hyperspectral and LIDAR sensors are commonly used during the exploration phase. Resource exploration begins above ground, with large area surveys that are accomplished using a helicopter or a fixed-wing UAS capable of covering large areas during a single flight, carrying EO or hyperspectral sensors (Kirsch et al., 2018; Park & Choi, 2020). These surveys provide prospectors with video or spectral signatures of an area used to determine the most resource rich portions of the landscape. Classification systems based upon the spectral characteristics (Beretta et al., 2019) and magnetic signatures (Jackisch et al., 2019; Parshin et al., 2018; Stoll & Moritz, 2013) of the landscape correlated to rock formation types have been developed for some locations, effectively creating a low cost matrix of likelihood for specific resource types. In 2019, Jackisch and others took this data fusion analysis further, and demonstrated that UAS-based surveys were 20 times more efficient than ground-based surveys for the same elements of interest.

During the exploitation or extraction phase, many of the same surveys are employed as during exploration, but with a slightly different reason. For example, 3D models are also created and used during the exploitation phase, but to infer slope stability or dam integrity for mining wastewater holding ponds during extraction (Beretta et al., 2019; Chirico & DeWitt, 2017; Dering et al., 2019). These methods are exceptionally useful when monitoring large, open-pit mines that previously were surveyed using ground-based methods that are comparatively expensive and time consuming (Lee & Choi, 2018; Park & Choi, 2020). Similarly, the infrastructure that is constructed and used for resource extraction are monitored for integrity using the same tools used for infrastructure monitoring in other circumstances; roads supporting resource extraction are monitored for stability using EO and LIDAR sensors to create orthomosaics, and production and delivery pipelines are monitored for breaches using infrared or gas analyzing sensors.

Human safety for workers in and around mines can also be supported by measurements from sUAS. Ground subsidence as an indicator of mine stability is monitored using 3D mapping techniques, and air quality measurements are critical to ensure worker safety. Both of these safety components can be supported by sensors flown on sUAS. LIDAR or EO sensors flown on sUAS to create 3D orthomosaics using SfM processing techniques can be regularly scheduled for continuous monitoring of a mine site (Park & Choi, 2020; Turner et al., 2020).

Air quality in the mine environment is a large variable that can impact the health and safety of the miners, as such, it is heavily monitored. Stationary air samplers are ubiquitous, as are sensors carried by the miners themselves but sUAS can also be used to monitor air quality in underground mines. UAS can carry sensors to directly sample the air for common hazardous gases associated with mining like sulfur oxides, carbon monoxide, carbon dioxide, and radon, and can be used in a reconnaissance capacity to increase miner safety. Utilizing the unique spectral characteristics of compounds hazardous to human health, hyperspectral sensors can provide qualitative and quantitative information used to determine the personal protective equipment needed to work at any given mine site (Alvarado et al., 2015). Broader spectral characteristics of these compounds can be ascertained using multispectral sensors (Turner et al., 2020), but also important to human health is the dust, its particle size and its chemical constituents, all of which can be measured using UAS outfitted with different sensors and samplers. Though sUAS are a valuable tool for performing mine air quality reconnaissance, the efficiency of UAS to monitor air quality as opposed to stationary sensors throughout the underground mining environment has not been demonstrated (Ren et al., 2019; Villa et al., 2016).

Monitoring the long-term impacts of abandoned mines and waste stockpiles using remote sensing techniques promotes health and safety of the environment and of the people performing those monitoring tasks. Traditionally, abandoned mines and the affiliated waste was monitored by field technicians collecting soil and water samples to measure contaminants and how they change over-time. Utilizing remote sensing tools reduces the amount of exposure to harmful chemicals during site monitoring. For the large-scale, open pit type of mines, satellite monitoring can be used to broadly monitor the area for landscape changes and general water quality parameters. But to gain the high resolution information about the land and water conditions of abandoned mine sites, UAS are an ideal tool. Multispectral sensors can be used to determine vegetation health as compared to the surrounding landscape to identify successful and unsuccessful reclamation solutions (Berni et al., 2009; Park & Choi, 2020; Song et al., 2020). Monitoring ecological restoration via water pollution, soil pollution and ground subsidence using UAS can be accomplished through observational sensors and physical samplers for air, water, soil (Song et al., 2020). Hyperspectral sensors are widely used to determine soil and water quality as impacted by mine sites (Fang et al., 2019; Jackisch et al., 2019; Park & Choi, 2020), either in the on-site wastewater pits, or by monitoring downstream conditions for breaches in containment. Monitoring mine sites for evidence of subsidence can be accomplished using differential interferometry from synthetic aperture radar sensors mounted on airplanes or satellites (Ng et al., 2017), but for UAS-based surveys, SfM techniques from either EO or LIDAR surveys are more popular. Subsidence from underground mines was measured by Dawei and others in 2020 using EO cameras and SfM processing techniques to obtain 3D surveys of subsidence areas (Dawei et al., 2020). The same techniques can be used to monitor subsidence of tailings piles, and long-term subsidence of reclaimed sites (Park & Choi, 2020).

### 1.5.8. WILDLIFE SURVEYS

Wildlife is key to the subsistence lifestyle of many rural Alaskans. Different wildlife species and life habits are displayed across Alaska, with a heavy seasonal component to where these animals are located on the Alaskan landscape. Satellite based monitoring solutions for Alaskan animals are limited due to resolution constraints of the sensors on-board the aircraft as well as the frequency any given area is imaged, approximately once every 14 days. As such, satellite-based remote sensing solutions have been limited to large mammals and for habitat delineation. Manned aerial surveys to ascertain populations of animals over a large area and have traditionally been accomplished using human visual observers. These traditional surveys are expensive due to fuel and aircraft costs, but also in the level of risk undertaken by biologists flying in small planes on a regular basis (Sasse, 2003). In cases where animals are smaller and habitat differences more nuanced, the higher resolution, near real time, low cost, and low risk data solution afforded by using UAS is a clear benefit of using this technology to monitor numerous components of wildlife studies.

When remote sensing animals from manned or unmanned aircraft, EO and infrared sensors are the most common and mature of the sensors used (Linchant et al., 2015; Wich & Koh, 2012). These sensors are highly developed and intuitive, allowing for straightforward surveys of animals with many software programs to support post-flight product creation. Challenges to animal observations using UAS are based upon resolution of the sensor and resulting imagery and animal contrast from the surrounding landscape or seascape. EO signals can penetrate the upper surfaces of clear water bodies, but generally, electromagnetic signals from targets below the surface of the water cannot be sensed by aerial sensors, whether passive or active sensors. Sensor resolution is also key to identifying animals that are not large in size, but that could be easily disturbed by a UAS, like a nesting duck. Using infrared sensors allows for identifying animals against the background of the landscape when the temperature differences are significant, but do not normally provide the resolution required for species identification. UAS have been used to ascertain body length and mass and to make assumptions about overall animal health using photogrammetry methods. Manual measurements of mammals can create dangerous situations for the animals as well as those trying to measure them. Utilizing UAS for these types of physical observations reduces the risk of harm to both animal and researcher, but also reduces stress impacts on the animals. Using traditional photogrammetric methods with EO sensors, numerous studies have highlighted the value of using the high resolution data collected by small, multirotor UAS as a non-invasive way to measure marine mammals (Krause et al., 2017; Perryman & Lynn, 2002).

Unique opportunities to use drones as “data mules” also exist. Wildlife telemetry is normally accomplished using radio collars on animals that provide a signal of their location when biologists, often flying in manned aircraft, fly near enough to them to pick up the individual animal collar signal. A new take on this same technology is to have the radio receiver be mounted to a UAS instead, reducing the risk to biologists, and increasing efficiency in radio collar data collection (Wich & Koh, 2012). Fixed wing UAS are better suited for missions like these due to the large area to be covered. Automated algorithms for detecting and counting individuals or groups of animals are also under development (Kellenberger et al., 2017), but are most valuable when there are known locations where animals are congregating such as a ranch or other key locations, like traditional breeding grounds.

One major concern about using sUAS to monitor wildlife directly is the potential impacts on the animals themselves. Guidance from resource trustee agencies like U.S. Fish and Wildlife Service (USFWS) or NOAA’s National Marine Fisheries Service (NMFS) lacks consistent guidelines for flying over or near animals with sUAS. Except in scenarios when no flight over animals is permitted at all, confusion over vertical and horizontal distances to be maintained between the animal and sUAS is often debated rather than mandated. Additionally, different animals react very differently to the presence of sUAS. Studies over marine wildlife in Alaska have shown that male marine mammals are less sensitive to the presence of sUAS than females, or groups of animals containing young (Angliss et al., 2018; Verfuss et al., 2018; Garron, unpublished). Birds react differently than mammals and are impacted by the lifecycle stage they are in when encountering a sUAS. When nesting or molting, birds are less likely to visibly react to the presence of a sUAS because of protecting the nest, or because they are physically unable to leave. Birds also react negatively to sUAS that are shaped similar to a raptor, natural predators for many birds. These situations cause great stress on the birds which in turn can impact longevity.

One of the often cited concerns of wildlife trustee agencies is sound and the impacts of UAS sound on the animals being observed. In 2018, a hydrophone was suspended 1m below the ocean surface in Kachemak Bay, Alaska to capture the sounds of three, small, quadcopters. Buzzing from the aircraft was detected by the hydrophone when UAS were flown up to 100 feet above the sea surface (Garron, unpublished). Similar sound propagation research performed off the coast of Australia revealed the same trend, but researchers speculated that the low frequencies used by whales likely precluded these noises from actually harassing whales, if they could even detect the frequencies (Christiansen et al., 2016). Noise impacts on animals are starker when flying over terrestrial animals or those hauled out of the water, as the reactions are visible to pilots and observers. Fixed-wing aircraft tend to be quieter than multirotor vehicles, but fly faster and cannot hover, reducing their utility to large animal surveys and habitat mapping missions. General habitat assessments are easily accomplished using sUAS with EO sensors capturing either still images or video (Johnson et al., 2015), but numerous other sensors are available to support the landscape and seascape habitat studies (see **Section 2.5.1-2.5.7, and 2.5.9**).

### 1.5.9. PLANT COMMUNITY MONITORING

Aerial remote sensing of vegetation has been popular since the launch of the Landsat satellite in 1972 (Goward et al., 2001). Large-scale vegetation trends that can be imaged from space are valuable for global-level calculations like global carbon sequestration potential or broad analyses like the Normalized Difference Vegetation Index (NDVI). NDVI is an indicator of plant community health and seasonal variability, through the relation of plant biomass to photosynthetic activity (Madden et al., 2015; Matese & Di Gennaro, 2018), and is often used to ascertain impacts from wildfire, vegetation species monitoring, land-disturbance, and climate change related ecosystem monitoring (Johnson et al., 2015). Unfortunately, the sensors carried by satellites lack sufficient resolution to support quantitative analyses of small and medium-scale vegetation phenomena (Berni et al., 2008).

The high spatial, temporal and spectral resolution afforded by sensors carried on UAS supports the use of these tools for monitoring vegetation on the local and regional scale. Using infrared and multispectral sensors on various UAS, Berni and others were able to demonstrate the higher resolution capacity of UAS to support small and mid-scale vegetation indices including leaf area index, chlorophyll content, and water stress detection (Berni et al., 2008). It is important to understand that radiometric calibration and atmospheric corrections are still required when quantifying plant communities with UAS (Aasen et al., 2015; Berni et al., 2008), primarily for quality mapping and long-term monitoring of specific geographical areas. Using calibrated UAS-collected data, researchers have been able to identify habitat destruction regardless of source, and understand detailed information about plants including evapotranspiration estimates to quantify plant stress using infrared sensors as an example.

Electro-optical (EO) sensors are very valuable for visualizing plant health and other vegetation-based analyses due to the similarities to examining plants directly. For example, it is evident when walking through a forest when a particular tree has curled leaves due to a stressor. Similarly, it is easy to observe the same phenomena at the forest canopy level using an high resolution EO sensor on a small UAS, but the observations can be more expansive due to the speed advantages of aerial surveys. EO sensors can also be used to estimate plant height, often an indicator of plant health in agricultural settings, by using SfM processing techniques. Researchers have successfully measured the height of individual plants to determine overall crop height and anticipated crop yield (Berni et al., 2008; Madden et al., 2015; Shi et al., 2016), expanding UAS utility for plant monitoring to include forecasting.

Infrared data supports straightforward analyses of thermal signatures of the landscape, but also can provide unique information about plant health. Madden and others describe the use of near infrared sensors to monitor general plant vigor and health (Madden et al., 2015), but more specifically, thermal signatures of plants are directly tied to plant stress, i.e. the “hotter” plants are under more stress. The heat signatures of plants are a result of the amount of water within their cells, thus water stressed plants appear hotter in the infrared imagery (Vibhute & Bodhe, 2012). Thermal signatures of plants can be extrapolated for use in decision-making such as in precision agriculture (Tmušić et al., 2020), and for monitoring environmental change in naturally occurring plants. It is important to highlight that infrared sensors tend to have a lower spatial resolution than EO sensors, thus flying them on UAS supports the collection of higher resolution data sets via lower altitude UAS flights over targets of interest. Another consideration when using infrared data is the impact of sunlight on the heat signatures of the various targets, which is particularly pronounced at the transition periods between day and night.

Information about plants captured with multispectral sensors can provide unique biophysical data based upon the observed spectral characteristics, especially when combining spectral bands in new combinations (Madden et al., 2015; Hunt & Stern, 2019). Light absorption and reflectance properties of plants can be used and for identifying variability within a species (Matese & Di Gennaro, 2018), nutrient deficiency within a species (Lima et al., 2020), and also for plant species identification, when multispectral sensors are calibrated with field observations [Johnson et al 2015]. A more common application of multispectral imaging of vegetation is via the calculation of plant indices as indicators of vigor. NDVI calculations, traditionally obtained from satellite based imagery, can be created using miniaturized multispectral sensors on UAS, capitalizing on the advantages of higher resolution data and flexibility in the timing of data acquisition afforded by UAS. These UAS-based benefits also extend to the calculations of leaf area index and leaf chlorophyll content calculations based on the spectral characteristics of the plants as measured by multispectral imagers in close range (Hunt & Stern, 2019). Raw multispectral data captured by a UAS may be less intuitive to work with than EO or longwave infrared data, but the calculations for indices of plant health are well established, and can be adapted to data collected by a UAS.

The highly detailed spectral information available form hyperspectral sensors can be used for detailed vegetation analyses of the landscape by quantifying chlorophyll content, leaf area indices, and green biomass estimations (Aasen et al., 2015; Adão et al., 2017; Berni et al., 2008). Hyperspectral data can also be fused with 3D information to produce rich data sets having to do with vegetation health and canopy structure (Aasen et al., 2015). Though the detailed information available from hyperspectral sensors is unsurpassed, the data is challenging to work with due to its volume, complexity, its lack of dynamic range and the reflectivity of plants themselves as contributing confounding factors to its utility (Aasen et al., 2015). In addition, the spatial resolution of hyperspectral data is limited, as the point and scans collected have a narrow field of view to support the collection and retention of the complex spectral signatures.

LIDAR data can also be used for monitoring plant communities. Three-dimensional structure of canopies is well documented for LIDAR, and the miniaturization of these tools to perform high-resolution, localized analyses are used for biomass estimations and forest compositional analyses (Bouvier et al., 2017; Madec et al., 2017). LIDAR has also been demonstrated valuable in detecting plant community changes, such as shrub encroachment (Madsen et al., 2020), a known impact of climate change in northern Alaska. One of the benefits of using LIDAR to measure vegetation is that the sensor is not sensitive to atmospheric influences of temperature and light that can impact infrared and multispectral data acquisitions. Another benefit is that the LIDAR signal can penetrate deeper into a forest or tundra canopy as compared to an EO sensor, allowing for the creation of more details 3D maps (Madec et al., 2017). However, the massive amounts of data collected by LIDAR are not insignificant, and reflect the power requirements of the sensors, and fundamental complexity of LIDAR data processing. When LIDAR is flown on a UAS, the most efficient applications are for large-area surveys typically conducted with a fixed-wing UAS that are capable of providing greater power to their respective payloads (Starek et al., 2018).

# 2. METHODOLOGY OF STUDY COMPONENTS

## 2.1. UAS OPERATIONAL SOLUTIONS MATRIX - METHODOLOGY

To synthesize current commercial off the shelf sUAS payloads, aircraft, and post-processing software solutions available to address climate change impacts in coastal Alaska, a matrix of sUAS operational solutions was developed. The UAS matrix is divided into low, medium, and high cost solutions for four of the nine science areas; coastal erosion, flood preparation, water quality monitoring, infrastructure inspection. A detailed examination of which of the proven sensor types that have been successfully miniaturized for use on a UAV and which UAVs can support them were identified, along with processing software to support the collected data sets. Each of the UAS matrix solution blocks identifies both non-US made and US made aircraft, sensors, post-processing solutions, and an estimate of the minimum amount of training that would be required for successful flight using those systems. Training requirements are based on the amount of time and number of trainers that would be required to train a novice UAS pilot on the operation of the aircraft, payload, and post-processing software identified solution block. Operational details about the aircraft, sensors, and software are included as are comparative estimates for the same data collected by a vendor using either a sUAS or manned aircraft system. The solutions identified for the four science areas are translatable to the remaining five scientific study areas, as none of the technology described was designed for specific scientific data set collection, except for the in situ gas samplers used for air quality analyses.

Three information collection strategies were synthesized to create the UAS matrix: a literature review of current sUAS used to collect quality data (see **Section 1.5**), a review of publicly available sUAS costs and specifications, and estimates from private companies for data collection over linear and large areas of coastal Alaska based upon the parameters of **Table 2**.

**Table 2 – Estimate requests from contractors for comparison in UAS matrix.**

| | Linear | Area | Vertical |
|---|---|---|---|
| **LIDAR**<br>a. Manned flight collection<br>b. Unmanned flight collection | 10 miles of coastline, three different collection periods per year, 3D models and map product | Two square miles of tundra, two different collection periods per year, 3D models and map product | Two acre water tank farm, one collection per year, 3D models and map product |

| | | | |
|---|---|---|---|
| **Multispectral**<br>a. Manned flight collection<br>b. Unmanned flight collection | 10 miles of coastline, 3 different collection periods, 3D models and map product | Two square miles of tundra, two different collection periods per year, 3D models and map product | Two acre water tank farm, one collection per year, 3D models and map product |
| **EO (RGB)**<br>a. Manned flight collection<br>b. Unmanned flight collection | 10 miles of coastline, 3 different collection periods, 3D models and map product | Two square miles of tundra, two different collection periods per year, 3D models and map product | Two acre water tank farm, one collection per year, 3D models and map product |
| **Relevant applications** | Coastal erosion, flood preparation , infrastructure monitoring, water quality, cultural and historical site identification and monitoring, wildlife surveys | Flood preparation, infrastructure monitoring, air quality monitoring, cultural and historical site identification and monitoring, extractable resource identification, wildlife surveys, plant community monitoring | Infrastructure monitoring, air quality monitoring |

## 2.2. ONLINE TOOLS COMPARISON METHODOLOGY

Recognizing that establishing a UAS program in a community might be too expensive yet data is needed for planning purposes, the Model Forest Policy Program researched whether online climate tools exist that provide data somewhat comparable to data collected locally by the use of drones and sensors. This research resulted in the creation of a matrix with samples of existing online tools that could help communities gather climate-related data (eg., historical, real-time, and projected). The final matrix is organized primarily by the nine scientific study areas. (**Please see Appendix B for the full Online Tools Comparison Matrix.**)

**Process 1 → 2 → 3**


The process to develop the matrix included 3 steps:

- **Step 1 - Research Existing Templates and Modify to Project Needs**
  First, online research was conducted to see if any websites and/or templates existed that compared online tools. Two useful sites were found and were drawn upon:
  - California Landscape Conservation Partnership (CA LCP) Tools for Assessing the Impacts of Climate Change (http://climate.calcommons.org/list/tools); and
  - Sea Level Rise and Coastal Flood Web Tools Comparison Matrix (https://sealevel.climatecentral.org/matrix/national.html?v=1).

  After reviewing these sites, members of the Project Team worked together to create a matrix that fit the project needs plus parallel the UAS Operational Solutions Matrix (**Appendix A**).

- **Step 2 - Research Online Tools**
  Next, federal and state agencies such as National Oceanic and Atmospheric Agency (NOAA) and University of Alaska - Alaska Center for Climate Assessment and Policy (ACCAP) were contacted for suggestions for the most relevant climate-related tools for coastal Alaska, especially Northwestern Alaska and the Norton Sound area, as a place a to start.

- **Step 3 - Populate Matrix**
  After starting with the recommended online tools, further tools were researched and many more added. From a variety of sources, a list of online tools pertinent to climate change and coastal Alaska was generated and each tool placed under relevant study areas. The developed matrix teased out the details below for each tool:
  - Was the tool applicable to one or more study areas
  - Geographic scope
  - Theme
  - Audience
  - Date of the data collection
  - Estimated time required to use the tool
  - Computer bandwidth required

A list of over 63 tools was generated and inserted under each of the 9 study areas, plus two additional categories - Permafrost and Collection of Tools. The matrix also indicates whether the tool can be found on the U.S. Climate Resilience Toolkit site (https://toolkit.climate.gov/).

The matrix-completed-to-date is by no means an exhaustive list; merely a sample. Not unexpectedly, some study areas, like erosion, have many tools; while other study areas, like wildlife surveys and plant communities, have few. While the initial list of tools focused on western and coastal Alaska, the list quickly expanded to being applicable statewide and some globally. If future funding is secured, the goal is that the matrix (currently an Excel spreadsheet) can be transformed into a living document/online resource toolkit for other Alaska communities.

## 2.3. ENVIRONMENTAL MONITORING WITH UNMANNED AERIAL VEHICLES: COST ESTIMATING & ANALYSIS METHODOLOGY

Barbara Cozzens of Whistling Thorn Strategies conducted the literature review and analysis for the project's Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis (Cost Estimating & Analysis) report. **(Please see the Appendix D for the full report.)**

The **goal** of the study was to estimate and compare the costs of UAS-based monitoring to other, more traditional, data collection approaches. Such analyses can provide communities, decision-makers, and staff with valuable information to help inform and strengthen decisions related to data collection system(s) for long-term planning for climate change and resilience.

Cost estimates were derived using analogous estimating, whereby historical data for similar activities or projects are used to estimate the cost of the planned project. Values were expressed in the same currency, standardized to the same scale (where possible), and inflation-adjusted. The following were calculated for each of the nine scientific study areas:

- Analogous cost estimates for drone monitoring relative to traditional methods;
- Cost comparisons delineated by study area and by research target(s), where applicable (ex. wildlife → large mammals, birds, salmon);
- Where feasible, values parameterized to a per-unit cost. For example: per hectare or per sample; and
- The accuracy or other effectiveness trade-offs documented where known.

Cost Estimating & Analysis report assumptions included:

- Technological advances will improve production efficiencies and costs. UAV/drone technology is changing rapidly. When fielded, these new capabilities may change the cost or accuracy comparisons dramatically.
- Not all methodologies are scale neutral. For example, manned aerial surveys will have a

minimum fixed or upfront barrier before costs scale, either by size of the area or by time involved. Similarly, satellite-based methods require a minimum buy of 50 km2. Where such minimum limitations are known, these are incorporated into the scalar cost.

- Drawing direct comparisons between methodologies is challenging. Which solution is most cost-effective depends on the management or research requirements.
- Every effort has been made to minimize transfer errors, but they should be anticipated. Such errors result from dissimilarities between the study site and the policy site, the method used to transfer values, lack of consistency in reporting scales, errors in rescaling, and researcher reporting or calculating.

A summary of the Comparative Cost Analysis study methodology follows:

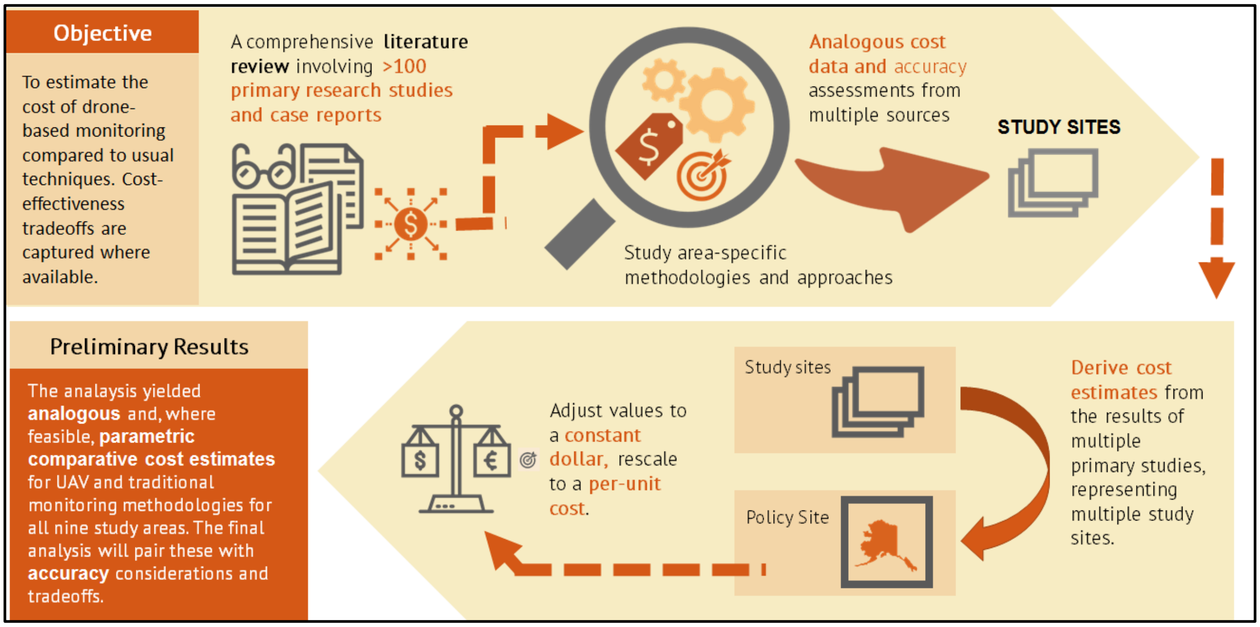



**Figure 4 - Cost Estimating & Analysis Methodology Overview.**

*Barbara Cozzens, Whistling Thorn Strategies (2020)*

## 2.4. UNALAKLEET FEASIBILITY STUDY PROJECT SURVEYS METHODOLOGY

In **February 2020**, as part of the Project Team's presentation at the Alaska Forum on the Environment, a very simple survey was developed for workshop participants with the following 6 questions:

- Prior Unmanned Aircraft Systems (UAS) Experience?
- Please prioritize what you see as your community's biggest concern? (1 - Highest to 9 - Lowest.)
  - Coastal Erosion
  - Flooding
  - Infrastructure
  - Water Quality
  - Cultural & Historical Sites
  - Plant Community
  - Wildlife
  - Air Quality
  - Extractable Resources
- Other areas of concern?
- Would you like an invite to the Spring Webinar?
- Interested in additional follow-up on the project?
- Please enter your contact information if you would like to stay involved in the project (Optional)

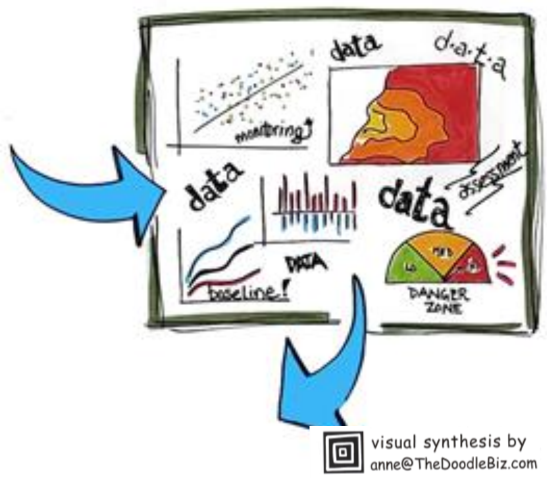
This survey was distributed during the Team's 2020 AFE presentation. A web link and QR code were also provided allowing people to enter their responses online. The **goal of the February 2020 survey** was to gain a sense of the audience's experience/knowledge using unmanned aircraft systems and an understanding of their community's concern related to the nine scientific study areas. Responses to the **February 2020 survey** are discussed under the **Results Section** below.

The February survey was followed in **early April 2020** **(April Survey)** by a lengthier survey entitled "*Community Monitoring Priorities & Unmanned Aircraft Systems (UAS) Experience*." The survey was distributed by email to targeted listservs consisting of Alaska Native Village Tribal Council /City Council members, Indian Environmental General Assistance Program (IGAP) Coordinators, and others who might be interested in the project. The **goal of the April Survey** was to gain a further understanding of a community's use of data in long-term planning and decision making, the type of data used and by whom, knowledge of and interest in unmanned aircraft systems, and where in Alaska the respondent lived.

The April Survey, accompanied by a cover letter from the Native Village of Unalakleet Tribal Council President, was broken into the following three broader sections: **Your Community**, **Unmanned Aircraft Systems (UAS)**, and **Follow-up Questions**. Respondents could complete the survey online or return via fax.

Under **<u>Your Community</u>**, respondents were asked:

1) In what region of Alaska is your community? (Far North, Interior, Southwest, South Central Alaska, Southeast)?
2) What is your role in your Community, checking all that apply? (Tribal Council Member (Current or Former); City Council Member (Current or Former); Native Corporation Board Member (Current or Former); Tribal or City Program (General Manager/City Administrator Head or Staff member); Federal, State, Agency or Regional Organization; Tribal Non-profit; Academia; Elder; Other (e.g., student, community member, community worker)
3) From the list below, what do you see as your community's biggest concerns? Please rank these nine areas, 1 - Highest to 9 - Lowest. (Coastal Erosion, Flooding, Infrastructure, Water Quality, Cultural & Historical Sites, Plant Community, Wildlife, Air Quality, Extractable Resources)
   a) Are there other areas of climate change concern not mentioned above?




4) Of the nine concerns listed above, what data does your community use to make decisions about these concerns? Please check all that apply. (On-line data resources and tools; Data sets from agencies (e.g. DGGS, USFWS); On-site data collection (e.g. webcam, Unmanned Aircraft System, etc.); University provided resources; Traditional Ecological Knowledge (TEK); Other)
5) Do you see gaps in the data resources used for decision-making? Yes? No?
   a) If yes, please briefly explain the gaps that you see.

Under **<u>Unmanned Aircraft Systems (UAS)</u>**, respondents were asked:

1) Prior Unmanned Aircraft Systems (UAS) Experience? (None; Very Little (I have seen it before.); Some Experience (I have flown less than 10 times.); Experienced (It is part of my work or an avid hobby flier.);
2) Do you have any other comments related to UAS in your community?

Finally, under the **<u>Follow-Up Questions</u>**, respondents were asked:

1) Would you like an invite to the upcoming Webinar? Yes? No?
2) Are you interested in additional follow-up on the project? Yes? No?
3) Please enter your contact information if you would like to stay involved in the project (Optional):

Responses to the **April 2020 survey** are discussed under the **Results Section** below. **(Please see Appendix F for the Unalakleet Feasibility Study Project Survey (April 2020) summary report.)**

## 2.5. INTEGRATION AND APPLICATIONS OF UAS AND ONLINE CLIMATE TOOLS DATA – DOCUMENT REVIEW METHODOLOGY

The UAS Feasibility Study includes a number of document reviews to identify the potential range of applications for using UAS data and online climate data tools in various planning and report documents. The review process included the following steps:

1. Select for review a representative sample of commonly used climate-relevant and/or planning documents at local, regional, state, and federal jurisdictional applications;
2. Review each document to answer the following questions:
   a) What types of UAS or online tools data are or would be relevant to this type of plan or report?
   b) How can UAS or online tools data gathering and analysis be applied to the planning process or report writing?
   c) What decision making processes could be informed by UAS or online tools data?
3. Complete the **Integration/Application of Data into Planning Matrix** for each document to identify how relevant the data applications are to each of the 9 scientific study area topics.
4. Provide a brief summary narrative of the findings for each document. The findings presented include a description of the scale and purpose of the document; the potential uses of UAS and online tools data in creating the plan or report document; the potential benefits to the decision making process and positive outcomes from integration of UAS or online tools data; and the estimated relevance to the 9 scientific study areas.

A total of six planning documents were reviewed, including three at the local level, one regional level, one state level, and one federal level. The list of selected documents and review findings are summarized in the report narrative (**Section 4.2.2. UAS and Online Tools Data Application into Adaptation Planning and Decision Making**); the study area relevance details are recorded in the **Integration/Application of Data into Planning** matrix (**Appendix C**).

## 2.6. PARTNERSHIP OPTIONS/ CONSIDERATIONS METHODOLOGY

One of the objectives of the project was to research and analyze short and long-term cost sharing/partnership opportunities and identify agreement options. Initially, Hal Shepherd of Water Policy Consulting and Meghan "Sigvanna" Topkok, Staff Attorney at Kawerak, researched types of agreements (general contract, service agreement, subscription, MOA, other), taking into account that a UAS service may not be provided by Unalakleet but that another Alaska Native Village may entertain the possibility of setting up a similar UAS program. From the research, the following table was created.

| Types of Agreements for Future Unmanned Aircraft Systems Data Collection Services | | |
|---|---|---|
| **Contractee (Retention of Services) or Funding Entity** | **Contractor (Provides Services) or Funding Recipient** | **Type of Agreement (Memorandum of Agreement (MOA), Contract, Cooperative Agreement)** |
| E.g. Native Village of Unalakleet | Consultant providing the service | Can be MOA or contract |
| Community XYZ or Regional Non-Governmental Organization (NGO) | NVU - to collect data | MOAs or contract |
| Agency XYZ | NVU - to collect data | MOAs or contract |
| Partnership | | Partnership Agreement (Formal business structure, generally registered) |
| Multiple Parties | | Cooperative Agreement - Generally based on government-to-government collaboration (Typically an MOA, depending on number of parties and what is being agreed to) |

Second, a partnership template was developed, based on a Memorandum of Understanding (MOA). The MOA was chosen because it is less formal and potentially a more appropriate agreement between Tribal and other entities.

Further, the developed template:

- Defines (UAS) terminology, data-to-be-collected and analyzed, and protocol(s) needed for specified region or location.
- Identifies parties (Contractor (UAS service provider) and Contractee (e.g. Community, federal or state agency, and/or other entity).
- Clearly spells out obligations and ownership/ custody of raw and analyzed data.

Related to the last bullet above, discussion around the template acknowledged that some data collected may be culturally sensitive but, simultaneously, exceptions for the communities health and safety, may need to be disclosed. If Tribes have concerns, a Data Management system should be considered and such details clarified. (**Please see Appendix E, Contractual Considerations - Example of Professional Services Language.**)

# 3. RESULTS

The following section is broken into two main parts, Overall Results and Synthesized Results for the Nine (9) Scientific Study Areas. The first provides an overview for the results related to Unmanned Aircraft Systems (UAS), Online Tools Comparison Matrix, and Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis. The second is organized by the nine scientific study areas (Coastal erosion, Flood preparation (river and sea), Infrastructure, Water quality, Air quality, Cultural and historical sites, Extractable materials, Wildlife, and Plant community) under which specific unmanned aircraft systems, cost comparison analysis, and online tools comparison results are discussed. **Note** that the costs related to specific UAS identify start-up/initiation costs for monitoring the various study areas; those related to the cost comparison analysis identify operational costs and how they compare to manned and ground-based monitoring of the study areas.

## 3.1. OVERALL RESULTS

### 3.1.1. UNMANNED AIRCRAFT SYSTEMS (UAS) OVERALL RESULTS

#### UAS INVENTORY AND MONITORING CAPACITY

Numerous sUAS were identified that have demonstrated the capacity to support environmental decision-making (**Section 1.5**). Sensors using a broad range of the electromagnetic spectrum are available for data collection and have been successfully miniaturized for sUAS flights. The data collected from these observational sensors can be georeferenced and subsequently processed to create high resolution orthorectified maps of an area. These data collection flights and orthorectified maps can be used as baseline data sets for change detection monitoring of different environmental compartments in a community or region. Key to the success of these sUAS data collection and product creation operations are the thoughtful selection of aircraft and accompanying sensor payload to answer the specific environmental question at hand.

Fixed-wing or VTOL UAVs are the most efficient vehicles for collecting long-range survey data, linear or area-based, but remain limited to line-of-sight flying. Line-of sight is at most two miles for most pilots and radio systems. To fly beyond visual line of sight (BVLOS), the UAS pilot needs to obtain a waiver from the FAA, inclusive of several safety cases and mitigation measures. Flying BVLOS is not recommended as part of a standardized local monitoring program under the current technological and communication regime for sUAS, but may be required under emergency response scenarios.

**UAS Operational Solutions Matrix, Appendix A,** identifies UAS solutions categorized as low, medium or high cost solutions for addressing the scientific study areas. The aircraft represent both Chinese and non-Chinese manufactured aircraft, built-in sensors versus those requiring engineers for integration, and a wide range of solutions from simple to complex. Many tools of various complexities exist for monitoring the scientific study areas addressed in this study. The

**UAS Operational Solutions Matrix (Appendix A**) identifies sensors, platforms, processing software and the minimum training requirements (in terms of time and cost) for UAS-based technology that can be used to collect environmental data to monitor environmental changes. The four scientific areas identified as most critical for monitoring climate change were thoroughly explored to include ground-based data collection techniques, locally implemented UAS-based solutions, contracted UAS-based solutions, and contracted manned aircraft survey operations to provide a holistic comparison of available survey tools. The solutions identified for the four science areas are translatable to the remaining five scientific study areas, as none of the technology described was designed for specific scientific data set collection, except for the in situ gas samplers used for air quality analyses. These synthesized results reflect the literature review of remote sensing solutions for the nine scientific study areas (**Section 3.2**), as well as the results of direct communication with UAS vendors and service providers. **Appendix A** is intended to be used as an operational decision-making guide for sensors and aircraft appropriate for localized UAS data collections.

## POST-PROCESSING SOFTWARE PACKAGES

The collection of quality UAS data is a significant part of performing change detection surveys, but the creation of orthorectified maps and other data products for change detection analyses requires additional software and post-processing routines. A set of different software packages that can be used to create maps from sUAS collected data were identified as part of the literature review reported on in **Section 1.5**, and were examined in detail as part of the UAS Operational Solutions Matrix **(Appendix A)** development process.

The identified software package costs are variable based upon licensing plans and range from $0 to $10,000 a year. Software licensing agreements exist for academic and tribal usage that may be appropriately used for coastal Alaska surveys at a fraction of the commercial licensing costs. Most of the software packages are focused on images, frames or point clouds, with the addition of several video processing software solutions.

- **Adobe Photoshop** is a popular photograph processing suite with many different utilities. It is not designed to incorporate geospatial metadata, but if a direct review of the UAS-collected images without georeferencing is all that is required for the final product, then this is a cost-effective solution for creating attractive image displays.
- **Pix4D** is a commercial mapping software suite that fuses EO imagery with GPS metadata in the UAS flight logs to create data products for decision-making. Different Pix4D photogrammetric applications specific to the type of mapping or surveying work to be performed are available and include a robust user community and support network.
- **DroneDeploy** is an app designed by DJI for use with DJI products. DroneDeploy can be used for flight planning and basic image processing through real-time and off-line connections to DJI cloud-based servers. DroneDeploy is viewed as a potential

cybersecurity threat to the US and US federal agencies are prohibited from using this application.

- **FLIR (Forward-looking infrared) Tools** is a software app designed to work with longwave infrared data (i.e. TIR data) collected with a FLIR camera. FLIR tools can be used with other TIR data collected by other TIR cameras, however the manipulations to the metadata that are required reduce the functionality of the tool suite and have the potential to introduce error. The app is designed to support the tuning of the infrared signature in the data, change color palettes for data display, and adjust temperature emissivity and reflection ranges in support of PDF report creation.
- **Agisoft Metashape**, formerly known as Agisoft PhotoScan, is a low-cost, relatively straightforward, post-processing software that supports the creation of orthorectified maps from UAS collected imagery using photogrammetric processing techniques. The resulting maps and 3D spatial data can then be exported for additional analyses in ArcGIS environments for resource identification, monitoring and change detection analyses.
- **ArcGIS Pro** is the most robust of the current ArcGIS operational platforms. Licensed for team or individual use, ArcGIS Pro has all of the functionality of ArcGIS desktop and ArcGIS On-line, as well as the capacity to integrate with both platforms. This powerful software package supports 2D, 3D, and 4D mapping with supporting metadata and informational geodatabases.
    - **Digital Shoreline Analysis System** is an add-in to ArcGIS that is used to perform erosional analysis. Originally developed by the USGS, this tool allows for meters per year calculation of erosion-based changes to an area. This tool can be used to automate post-processing of shoreline analyses while integrating forecasting models for risk and sensitivity analyses of particular sections of coastline.
    - **Full Motion Video** is within the Image Analyst extension to ArcGIS Pro to support real-time and archived video analyses for change detection. Videos with embedded georeferenced metadata can be fused with the other metadata for rich and repeatable analyses using this tool.
- **ArcGIS on-line** is a low cost solution for straightforward ArcGIS map support. The benefits of ArcGIS on-line are that it is always up to date; a comprehensive on-line support community exists for its operation. Drawbacks are that it does not support a number of the sUAS specific post-processing packages like the Digital Shoreline Analysis System nor the Full Motion Video extension available in ArcGIS Pro.
    - **Drone2Map** is an ESRI product that uses UAS-collected EO data to create orthorectified 2D and 3D maps in the ArcGIS environment. Drone2Map is capable of integrating Pix4D workflows for increased product richness or attribute display.

- **Non-commercial proprietary software** packages also exist for all sensors analyzed here. Non-commercial proprietary software packages should be avoided if possible due to the lack of consistent support for their operation and updates. Most commercial off the shelf sUAS solutions have corresponding commercially available software solutions for data post-processing, complete with support teams.

An important consideration when determining which software package is most suitable for the sUAS data collected is the computing power and operating systems required to run them.

### 3.1.2. ONLINE TOOLS COMPARISON OVERALL RESULTS

**Background:** Alaskan communities have available an array of free environmental and climate tools developed by government agencies, science groups, universities, and other tribal organizations. Unfortunately, these tools are often a challenge to find, time consuming, complicated, data heavy, and it is not always clear whether a given tool is (a) relevant to the particular challenges faced by a community, (b) applicable to the specific geography of the community, and (c) usable by a community given other constraints.

**Process:** A moderate sample of Alaskan coastal related climate tools were located online, described in an Excel Spreadsheet under the nine scientific study areas with the addition of two other categories - Permafrost and Collection of Tools. Sixty three tools were located, with the majority of tools in these study areas: coastal erosion, flooding, and water quality. A limited number of tools were found for plant communities monitoring, wildlife surveys, cultural and historical sites identification and monitoring.

**Results:** The spreadsheet of tools can be found in **Appendix B**. Results for the individual scientific study areas are found in **Section 3.2. Synthesized Results for the Nine (9) Scientific Study Areas**.

**Future:** Once the spreadsheet was populated, it became clear that the resource should be made available to Alaskans and kept alive, located where people can add to over the coming years. The overall project and spreadsheet were presented to the Alaska Native Tribal Health Consortium (ANTHC) as a potential home for the resource. Collectively, the Native Village of Unalakleet (NVU), the Model Forest Policy Program (MFPP) and ANTHC decided a future project together was worth exploring. A draft scope of work and budget were developed. Unfortunately, the timing is not good for ANTHC, hence another home needs to be sought for the climate tools list that could benefit community climate adaptation planning across Alaska. Possible entities that could be approached to be such a home are the University of Alaska Fairbanks - Alaska Center for Climate Assessment and Policy (ACCAP) or Scenarios Network for Alaska + Arctic Planning (SNAP), both part of the International Arctic Research Center; the U.S. Climate Resilience Toolkit; and/or possibly shared on a Norton Sound regional basis with Kawerak.

### 3.1.3. ENVIRONMENTAL MONITORING WITH UNMANNED AERIAL VEHICLES: COST ESTIMATING & ANALYSIS OVERALL RESULTS

Barbara Cozzens' Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis (Cost Estimating & Analysis) collates and systematically presents the fragmented data on UAV data collection and analysis costs, and utilizes this data to estimate costs specific to the nine study areas. Following are the key takeaways from the study (**Appendix D**).

- In at least four of the nine study areas, UAV monitoring and/or sampling was demonstrably more cost-effective than traditional methods. However, in many of the areas without a clear cost advantage, UAVs proved to improve efficiency of monitoring or sampling, provide access to remote or inaccessible areas, and reduce risks to human health and safety.
- Cost estimates were derived from historical data published in studies and reports addressing the same scientific study area. Though the Cozzens' report treats the study areas independently, the range of values should not be considered in complete isolation from one another. It is reasonable to view cost data for similar UAS applications outside of a given study area (ex. UAV SfM for coastal erosion and UAV SfM for extractive industry volumetric removal monitoring). Potential areas of cost/study area overlap are summarized in **Appendix D**, pg. D.3.
- Decisions concerning the application of UAV should assume some measure of economies of scale: A monitoring mission for one purpose can be used to generate data for another purpose, thus spreading costs over a larger number of objectives. Likewise, where capital costs are prohibitively high, a shared service would allow multiple agencies to reduce the cost of monitoring for all.
- While the gains offered by UAV data collection have been highlighted and in most cases empirically demonstrated, few details have been published related to costs to date. Given this scarcity of historical cost data, the number of study areas, and the variety of environmental contexts, scales, constraints, and variables that could be assessed with UAV systems, Cozzens determined that it was impractical to provide estimates with any measure of confidence. However, the estimates can serve as guideposts to help inform and strengthen decisions.

## 3.2. SYNTHESIZED RESULTS FOR THE NINE (9) SCIENTIFIC STUDY AREAS

This section is a description of the tools and how they relate to the information found in the literature reviews for the nine scientific study areas.

### 3.2.1. COASTAL EROSION MONITORING

***Objectives:*** *Identification and quantification of erosion-based coastal changes; identification and monitoring of erosion-prone coastal areas.*

**Unmanned Aircraft Systems and Cost Comparison Analysis**

Coastal erosion had the greatest number of supporting tools and previously collected datasets that could be applied to monitor changes both locally and regionally **(Section 1.5; Appendix A)**. Manual measurement (Emery Rod technique) was identified as the least expensive method when monitoring short lengths of coastline that did not require air travel to access. However, application of the technique on a broader scale would be time consuming and challenging in remote Alaska where few roads follow the coastline. The least expensive RS solution was a time-lapse camera, set in a stationary location, focused on a specific piece of coastline. This application is also plagued with the need for manual intervention (downloading) and is best suited for small lengths of coast, normally a mile or less.

To survey greater than a mile of coastline, aerial survey techniques can provide an efficiency advantage. Manned aircraft have traditionally been deployed to collect these data using high resolution cameras and LIDAR sensors to create orthorectified maps used in change detection. The cost to hire a contractor to survey approximately 10 miles of the Bering Sea coastline from Unalakleet in a manned aircraft with either a RGB or LIDAR payload was the most expensive solution averaging $50,000 per survey trip. Hiring a contractor to perform the same coastal surveys using a sUAS was slightly less expensive at $40,000 per survey trip (**Appendix A**).

The **Coastal Erosion** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.8-D.9, concluded that,

> *To overcome the limitations of traditional methods, UAVs are now being employed to monitor beach-dune morphological changes and beach morphodynamics (Brunier, 2016); reconstruct beach topography (Mancini, 2013); quickly assess storm impacts; and monitor recovery. UAS surveys allow for more immediate, flexible, and less resource-intensive deployment. When paired with [Structure from Motion] SfM, the imagery and derived topographic data are available at considerably higher resolutions and spatial point densities than other surveying methods, particularly in sandy beach areas (Sturdivant, 2017).*

*UAVs have reportedly been underutilized for coastal management (Sturdivant, 2017) [...]*

Please see the comparison matrix, *Analogous Costs and Parametric Cost Estimates for Coastal Erosion Monitoring: Costs Per Hectare (US$) Plus Equipment Costs*, contained in the full report, **Appendix D**.

The most developed workflow for monitoring coastal erosion with sUAS uses either EO or LIDAR sensors as payload (Section 2.5). Regardless of the sUAS vehicle, the collected EO or LIDAR data can be processed to create orthorectified maps that can be used for documenting coastal change due to erosional processes. These maps are built on point-clouds of either EO or LIDAR data that are used to create a digital surface model (DSM) of the area that is then referenced for the creation of the orthorectified maps. These DSMs are valuable as a stand-alone product for observing baseline conditions and those resulting from a change that impacts the DSM, such as melting permafrost. When multiple data sets over a defined section of coastline are combined with coastal forecast models and localized resource inventories, the resulting data products can be used to predict areas that are more vulnerable to erosion and should be more acutely managed.

## Online Tools Comparison

It is not surprising that the greatest number of online tools is found under the Coastal Erosion Scientific Study Area because of the increased risk presented to coastal communities. A total of thirteen tools were included on the Online Tools Matrix and found on these websites: National Oceanic and Atmospheric Administration (NOAA), Alaska Division of Geological & Geophysical Surveys (AKDGGS), Western Alaska Landscape Conservation Cooperative (LCC), National Drought Resilience Partnership (NDRP) comprises seven federal agencies, and U.S. Geological Survey (USGS). Six of the sites have near or real-time data; the others can provide data within the last decade. Only three sites are fairly quick to review/ navigate; six sites will potentially take quite a bit more time to research. The sites provide downloadable graphs and maps, digital geospatial data (shapefiles metadata), maps with multiple data layers, assessments, forecasts, tools, additional resources, reports, videos. Many of these sites because of the complexity of information may take longer to download and/or navigate.

The thirteen identified Coastal Erosion-related websites focus on: observed water levels; sea level rise; shoreline change; coastal (and river) flooding and erosion; habitat loss and gain due to deposition; beach elevation profile measurements; Alaska coastal physical and biological conditions; temperature and precipitation; and ice condition. An incredible amount of information is available on these sites but it takes time to decipher and determine if data is available for your community.

### 3.2.2. FLOOD PREPARATION (RIVER AND SEA)

***Objectives:*** *Identification of areas prone to flooding, new and old.*

#### Unmanned Aircraft Systems and Comparison Cost Analysis

Remote sensing tools, in specific UAS, have been proven for their utility to support decision-making about flood prevention, preparation and response. **Section 1.5** identified the most common UAS-based applications for flood support are to create 3D maps of an area to identify potential flood hazards due to low-lying areas and undefined potential flood channels, and for the monitoring of coastlines and river evolution inclusive of erosional events. The **Flooding** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.9-D.10**,** also concluded that,

> *UAVs can monitor river dynamics with a level of detail that is several orders of magnitude greater than satellite. They can also capture flow measurements over smaller river systems and tributaries and in difficult-to-access environments. On the whole, UAVs provide very high resolution and accurate digital elevation models (DEMs) with low surveying cost and time, as compared to DEMs obtained by Light Detection and Ranging (LiDAR), satellite, or ground-based GPS fieldwork.*

UAS-based solutions that can support flood preparation activities are categorized in **Appendix A** by low, medium and high-cost for initial implementation. These solutions are based on EO and LIDAR sensors that have the most developed protocols for data collection and 3D map creation on the meter scale, or smaller. Like costal erosion monitoring, the simplest remote sensing tool available for communities to monitor active floods or erosional events that can lead to flooding, is a time-lapse camera mounted on either a tower or building to provide an aerial perspective. Cameras like these are valuable as they are inexpensive to install and operate, but they are stationary and not geospatially calibrated, meaning that 3D map creation is not possible with this monitoring solution.

EO sensors integrated into low-cost UAS are available for less than $5,000. These sensors and aircraft are not designed to provide survey-grade information, but are of high enough quality to be valuable for real-time observations and general situational awareness. Some of these relatively inexpensive UAS can support the creation of 3D maps usable for volume calculations, by utilizing higher quality, higher cost, post-flight data processing software packages. Volume calculations can show where flood prone areas have emerged through erosional and subsidence events, and to help identify areas of active change. These map packages mimic the SfM processing used for highly detailed research and survey analyses, through simplified interfaces, with most data processing occurring in the cloud. The UAS outfitted with EO sensors and the more robust mapping software package solutions range in cost from approximately $5,000-$10,000 (**Appendix A**).

LIDAR and high quality EO sensors can supply decision-makers with the most detailed information about potential flooding and flood response actions, but also require the greatest amount of capital and training to utilize. UAS that can support LIDAR and precise EO sensors can cost as little as $4,000 for a basic multi-rotor vehicle that can carry customized sensors, to close to $100,000 for a UAS that includes a LIDAR sensor providing accurate, cm-scale, 3D maps (**Appendix A**). In comparison, manned flights (helicopter or airplanes-based) to collect landscape-scale surveys with LIDAR and high-resolution EO sensors are less expensive to contract than it is to purchase a highly accurate UAS-based solution. Decisions about data collection methodology, and thus the equipment to accomplish it, should be based off of the informational end goal of the decision-maker. If a one-time survey is all that is required, contracting a manned data collection flight may be the best solution. For long-term landscape monitoring, locally and regionally, high resolution UAS-based solutions are increasingly cost effective for monitoring landscapes actively changing. Additional analyses about long-term implementation costs can be found in the comparison matrix, *Analogous Costs and Parametric Cost Estimates for Flood Monitoring: Costs Per Hectare (US$)*, contained in the full report available as **Appendix D**.

Critical benefits can be realized with a localized, UAS-based solution, flood prevention observations that are less likely with periodic, contracted surveys. Flexing the capacity for real-time data collection flights, using the identified sensors and locally operated UAS in combination with weather forecasts, individual communities would have the tools to create customized storm surge advisory warnings for local decision-making. However, the map products created from the UAS tools are not currently used as part of a consistent UAS-based river or coastal monitoring program for flood prevention.

## Online Tools Comparison

A total of 10 tools were included on the Online Tools Matrix and found on these websites: U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), Alaska Division of Geological & Geophysical Surveys (AKDGGS), Alaska Native Tribal Health Consortium (ANTHC), University of Alaska Fairbanks. Half of the sites have near or real-time data; the other half has data that is within the last decade. Eight of the sites can be reviewed/navigated fairly quickly to become familiar with the information; the other two, a bit more time is needed. The outputs from the sites include downloadable/printable maps, data tables and graphs, analytic tools, short reports, and data summaries. Half the sites do not have large Mega Byte (MB) files so not over burdensome to download; the other half may take longer.

The 10 identified Flood Preparation websites focus on: current water conditions (e.g. surface water, water quality, ground water); flood preparation; infrastructure monitoring; flood inundation; temperature and precipitation; stream flow; storm surge; and local observations. The NOAA and USGS sites can provide real-time data if a community has an observation site. Unfortunately, such sites are somewhat scarce in Northwestern Alaska. The Native Village of Unalakleet does have such an observation station that monitors coastal inundation (NOAA, 2021). The AKDGGS website does provide color-indexed maps, for a handful of flood-vulnerable

Alaska coastal communities of which Unalakleet is one, using 2017 datasets. These maps can assist communications about forecasted water levels, local elevations, and potentially impacted infrastructure in advance of storm events that may cause coastal flooding. These maps are not designed to function as flood inundation maps, but as a communication tool about elevations in at-risk coastal communities until true inundation mapping can be completed (Overbeck et al., 2017). The data contained on these sites can provide a baseline for a community, but again, it is dependent on whether a community has an observation station or not.

### 3.2.3. INFRASTRUCTURE MONITORING

***Objectives:*** *Identify current state of key NVU [community] infrastructure.*

#### Unmanned Aircraft Systems and Comparison Cost Analysis

Traditional infrastructure inspections are conducted via manned aircraft, trucks, ATVs or other ground-based vehicles, or on foot. These inspections most commonly are direct observations by the inspector, in some cases employing a remote sensor such as a portable gas detector, to monitor the integrity of either production, delivery or storage assets for corporations and communities. The frequency of inspections varies by the infrastructure under examination, as do the compliance specifications.

The **Infrastructure** section of **Cost Estimating & Analysis** report, in **Appendix D**, pgs. D.10-D.11, also concluded that,

> *Thermography, ultraviolet cameras, airborne LiDAR and terrestrial laser scanning are also frequently utilized. The time, resources, and costs associated with these methods have led to an increasing backlog of maintenance activities.*

UAS are ideally suited for monitoring infrastructure due to the dirty, dull and dangerous components of the work. Regardless if the infrastructure is linear (e.g. roads, pipelines, utilidoors), vertical (e.g. gas compression plant, electrical substation, buildings) or a combination thereof, UAS can be used to safely document infrastructure for immediate and future analyses. The **Infrastructure** section of **Cost Estimating & Analysis** report, in **Appendix D**, endorses the use of UAS for infrastructure inspections by highlighting additional use cases,

> *UAVs have the potential to optimize the monitoring of buildings, electrical grids, oil and gas lines, roads, railways, dams, water reservoirs, airports, maritime routes, and bridges. For example, UAV-acquired visible and infrared images have been used to monitor the condition and structural health of bridges, including bridge deterioration, deck delamination, aging of road surfaces, and crack and deformation detection (Ellenberg, 2016). Likewise, UAVs have been applied to monitor power infrastructure, including power lines, poles, pylons, and power stations, through all phases of electric grid development (Xiang, 2019).*

The type of infrastructure under examination will dictate which UAV and sensor suites will be most valuable for the monitoring effort. **Section 1.5** identifies a few well documented strategies for using UAS to monitor infrastructure that have been integrated into the UAS matrix in **Appendix A**. One of the most straightforward and least expensive methods for infrastructure monitoring is the use of a time-lapse camera to monitor the asset of interest. This is a very reliable and repeatable remote sensing solution if the asset is static and the area of interest small. Other solutions for larger area inspections include using fixed-wing UAS to monitor miles of pipeline for thin spots in the pipe where escaping heat from the contents can be detected by infrared sensors. Hot spots can be displayed as spots on a static map, or documented through detected changes in a full motion video or orthomosaic analysis. High resolution optical sensors and LIDAR are good for identifying visible integrity and can be used to develop SfM change detection maps that can be especially valuable for road and bridge inspections, but low resolution optical sensors can provide general situational awareness when fine details are not a requirement. In situ gas samplers can be very valuable for detecting larger gas leaks, but are directly influenced by natural variables like wind, sunlight and precipitation, and have not been operationally integrated on commercial off the shelf UAS. Multispectral sensors are known for supporting inspections where imagery from both the visible and infrared portions of the electromagnetic spectrum are needed for decision-making, and have been optimized for both fixed-wing or multi-rotor UAVs.

At this time there is no single UAS solution to address all of the different infrastructure types or the variables influencing their integrity, but a combination of solutions will increase the reliability and repeatability of these types of inspections. To reflect the span of UAS solutions for infrastructure inspections, UAS in **Appendix A** have been categorized under low, medium and high cost solutions available for linear, area, and vertical infrastructure inspections. Contracted flights LIDAR or EO flights for high resolution mapping are the most expensive long-term remote sensing of infrastructure solutions. There is a range of visible, infrared and in situ gas samplers available with supporting training regimes that will allow for more frequent inspections performed locally for the same start-up costs or lower than one contracted infrastructure survey (**Appendix A**). Additional cost analyses for conducting individual flights can be found in the full cost comparison matrix report, *Analogous Costs and Parametric Cost Estimates for Road & Bridge Inspections: Costs Per Linear Foot (US$)*, **Appendix D**.

To reduce environmental variability of infrastructure inspections performed by multiple operators over time, **Section 1.5** highlights the importance of repeatable protocols as key for archiving infrastructure integrity through time. This repetition is achievable by using consistent flight plans, data post-processing routines and regular inspection flights for long-term asset management. This methodology allows for the establishment of baseline conditions of any monitored asset, as well as the opportunity for change detection analyses in the future. The successful protocols will be those written with the infrastructure stakeholders so that the pertinent targets will be examined to provide the data decision-makers can use for both short and long-term planning.

**Online Tools Comparison**

A total of 5 tools were identified and included on the Online Tools Matrix. Three of the five websites are run by the U.S. Energy Information Administration (USEIA); another site by Earth Scope - a multi-agency, university partnership; and the last, Climate Ready Infrastructure and Strategic Sites Protocol (CRISSP) (including a risk assessment matrix), run by the Great Lakes and St. Lawrence Cities Initiative. Three of the sites have fairly real-time data, while the other two contain data collected in the last decade. They all potentially take at least a half hour or more to become familiar with the site in order to locate relevant data. The output from the tools includes printable maps, tables, and matrices. The sites are somewhat GIS-heavy (map layering) so may take time to upload. The Earth Scope site focuses on monitoring seismic activity. The USEIA - Energy Infrastructure with Active Storms and Other Hazards helps to identify potential threats to energy infrastructure from significant storms and other weather events, flooding, and wildfires (USEIA, 2021b). The USEIA - U.S. Energy Mapping System for Alaska (and all states) shows various aspects of the U.S. energy infrastructure, including energy conversion sites, transmission pathways, and various energy reserves. The set of map layers includes fossil energy resources as well as geothermal, biomass, solar, and wind resources. Map layers also show coal mines, power plants, oil and gas refining and processing plants, market hubs, pipelines, and electrical transmission networks (USEIA, 2021a). Finally, USEIA - Flood Vulnerability Assessment Map, an interactive site, gives users a way to identify which assets of the U.S. energy sector are vulnerable to flooding hazards. The map shows flood hazard information from the Federal Emergency Management Administration along with energy infrastructure layers from the U.S. Energy Information Administration. State, county, city, and private-sector planners can use the map to assess which energy infrastructure assets are vulnerable to rising sea levels, storm surges, and flash flooding (USEIA, 2021c). These sites can provide a means of assessing potentially vulnerable community infrastructure, as well as a guide for assessing associated risks. They can assist with initial assessments but the shortcomings are the critical on-the-ground monitoring that may be needed with increased climate risks.

### 3.2.4. WATER QUALITY MONITORING

***Objectives:*** *Measure the spectral characteristics of water and pollutants to determine quality.*

**Unmanned Aircraft Systems and Comparison Cost Analysis**

Rivers and oceans in Alaska are crucial for sustaining human livelihoods via food security and economic development. As water resources are impacted by climate change and resource extraction, measurable components of water quality can help determine management strategies to support these user needs. Measures of water quality are used to determine and monitor organic and inorganic loading to any given water body. Understanding these balances and imbalances for a particular water body can support decision-maker’s management strategies key to community health and well-being.

**Section 1.5** identified that EO sensors are used to estimate phytoplankton abundance which can be used as a proxy for increases in nutrient loading due to either pollution or natural releases. Similarly, sediment loading which can be an indicator of permafrost thaw, excessive run-off or industrial loading can also be measured with EO sensors. Infrared sensors can be used to measure the heat signature of the water to identify heat pollution as either ubiquitous or point-sources. Multispectral sensors can also be used to observe these inorganic and organic constituents simultaneously through the multiple parts of the electromagnetic spectrum it can measure.

The **Water Quality** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.14-D.15, identified additional measures of water quality and also concluded that,

> *UAV-based instruments are now being successfully deployed for a wider variety of water quality-related assessments, including mapping submerged aquatic vegetation, surveying intertidal reefs systems, monitoring harmful algal blooms (Becker et al., 2019), assessing turbidity (Larson et al., 2018), detecting oil spills, and estimating cyanobacteria concentrations.*

EO, infrared, and multispectral sensors are relatively inexpensive and have well-developed post-processing workflows that make the using of these specific tools to measure components of water quality, either mounted in a static location or on a UAV, a relatively straightforward process for most users. A set of sensors and supporting fixed-wing, VTOL and multi-rotor sUAS solutions for measuring components of water quality are identified and binned by cost in **Appendix A**.

In situ samplers and hyperspectral sensors can also be used to determine water quality, but are more labor intensive and less developed than the EO, infrared and multispectral systems. **Section 2.5** highlighted Garcia-Pineda's work using in situ water samplers mounted to a multi-rotor sUAS to collect water samples to measure the amount of oil pollution. This same type of methodology could be used for determining baseline water quality or seasonal changes in water, the primary drawback being the time required for direct water sampling followed by laboratory analyses of those water samples.

In the **Water Quality** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.14-D.15, supported this assessment about in situ water sampling,

> *Many of these [traditional methods, e.g. grab sampling] methods are relatively slow, spatially restricted, expensive, or difficult to deploy; none can overcome barriers, such as land or dams. To overcome these limitations, Ore et al. (2013) developed a UAV-based water sampling system that could safely fly close to the water and collect three 20 ml samples per flight. Water properties of their UAV-collected samples matched those collected through traditional manual sampling techniques, in 1/6 the amount time.*

Hyperspectral sensors can also be used to determine water quality but will need to be calibrated specifically to the water body and pollutant of concern to be able to collect the correct spectral information. Neither of these two methodologies is well-refined, nor cost effective solutions for monitoring a wide variety of water bodies on a seasonal or otherwise regular basis. Specific discussion of cost effective water sampling solutions can be found in the cost comparison matrix, *Analogous Costs for Air Quality Monitoring: Fixed Costs (US$)*, contained in the full report, **Appendix D.**

#### Online Tools Comparison

A total of 6 tools were identified and included on the Online Tools Matrix. Three of the websites are found through the U.S. Geological Survey (USGS). The others are: Alaska Department of Environmental Quality Conservation Division; the Arctic Landscape Conservation Cooperative (LCC); and a cooperative service sponsored by USGS, EPA, and the National Water Quality Monitoring Council (NWQMC). Sites vary in their focus, time needed to get oriented, and bandwidth needed to download the information. Outputs include data summaries, maps, and bioassessments. Data can also be downloaded in a variety of forms including Excel spreadsheets and KML format. Data is not necessarily collected for all communities. For it to be so, data collection would need to take place in or around the community and that data shared with the agencies.

### 3.2.5. AIR QUALITY MONITORING

***Objectives:*** *Monitoring air quality for human and animal health.*

#### Unmanned Aircraft Systems and Comparison Cost Analysis

Alaskan air quality is often impacted by forest fire smoke due to the large number of wildfires that occur across the state each year. The most abundant pollutants of concern in wildfire smoke are the particulates that are less than 2.5 micrometers in diameter, also known as $PM_{2.5}$. Though other chemical compounds that can negatively affect human health are also present in wildfire smoke, these small particles can become deeply lodged in lungs, and in some cases cross into the bloodstream. Aerosols present in wildfire smoke and resulting from incomplete combustion of fossil fuels can also cause respiratory and pulmonary distress, especially in combination with particulates. In addition to the health impact of poor air quality, the haze that often accompanies wildfires and air pollution in general can be a safety hazard for transportation.

The most common and effective sensors for measuring air quality from a UAS identified in **Section 1.5** are spectrometers and particle counters. Commercial miniaturization of these sensors for measuring particle size and density is underway but not fully achieved, limiting the number of efficient and effective samplers that can be used on a UAS at this time. Samplers have moving parts and thus are also subject to the impacts of cold and humid conditions influencing their functional range. LIDAR data has also been used to measure air quality, but the extensive post-processing and subsequent interpretation cannot be accomplished in real-time, reducing the value of this tool to archival data collection. The algorithmic advances described in **Section 1.5** having to do with pairing EO sensors observing haze with stationary ground sources to develop a proxy for air quality indices are still prototypical, though promising for future applications.

The unmanned aircraft that can carry these sensors to obtain both vertical and horizontal profiles are the multi-rotor vehicles. These systems can provide the greatest versatility for sampling air in situ, but are limited in the geographic area they can cover during individual flights based on battery life, and the impacts of power draw by the air quality samplers. Larger fixed-wing aircraft can typically carry a heavier payload, but unless large area surveys are required, may not be the best solution for localized air quality data collection efforts.

The **Air Quality** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.13-D.14, similarly concluded that,

> *UAVs can provide more accurate information on aerosol distribution throughout the atmospheric column, which is needed to better understand air composition and quality in specific atmospheric layers (Villa, 2016). Compared to land-based methods, UAVs increase operational flexibility and resolution by covering larger areas and opening up remote, difficult to access, or dangerous locations to safe monitoring (Villa et al., 2016).*
>
> *UAV application to air quality monitoring is still relatively new, and the body of literature is thus rather small. In many cases, cost data is intentionally excluded. For example, the EPA has stated "cost information is not reported here, as the market prices of sensors are at the purview of the manufacturer or distributors, and may change with time or purchasing volume."*

Please see the comparison matrix, *Analogous Costs for Air Quality Monitoring: Fixed Costs (US$)*, contained in the full report, **Appendix D.**

## Online Tools Comparison

Three tools were included on the Online Tools Matrix and found on the Alaska Department of Environmental Conservation and The World Air Quality Project websites. Outputs are maps, tables and data. The World Air Quality Project site includes a real-time map indicating air quality globally. Unfortunately, only communities that are monitoring air quality are shown on the map. In Alaska, it appears to be mainly around Fairbanks, Anchorage, and Juneau. The 3 sites are fairly straight forward and downloading the information not too onerous.

### 3.2.6. CULTURAL AND HISTORICAL SITE IDENTIFICATION AND MONITORING

***Objectives:*** *Identification of structures and landscape anomalies that could be cultural resources; monitoring known cultural resources for change.*

#### Unmanned Aircraft Systems and Comparison Cost Analysis

The preservation and conservation of cultural and historical resources is important for maintaining the heritage of society. Not having been glaciated during the last ice age, Alaska has extensive prehistoric cultural resources, only some of which have been identified. In addition, Alaskans have been living on the landscape continuously for thousands of years, creating and modifying cultural and historical resources continuously. A new component to this dynamic is climate change and the resulting impacts to these resources through erosion, permafrost melting and subsidence as well as increased activity on the landscape. Performing extensive aerial surveys of the landscape with manned aircraft to identify these resources is not common due to the massive amount of area that would need to be systematically surveyed, and the resolution of data that would be required to make those determinations. Instead, using UAS to identify anomalous landscape features locally and regionally can identify resources that are at greater risk due to their proximity to communities or other areas of activity on the landscape, such as mines or other development projects.

The **Cultural and Archaeological Heritage** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.11-D.12, concluded that,

> *UAVs are utilized to conduct photogrammetric surveys and mapping for documenting and preserving archaeological sites. They're also commonly used spectroradiometer, digital or thermal cameras for the detection, discovery, and inventories of artifacts.*

These specific sUAS applications are well suited to historical archeological sites, but additional challenges exist when using these tools to identify prehistoric resources. Prehistoric cultural resources are made of the same materials that compose the Alaskan landscape today. As such, these artifacts do not have a distinctly different electromagnetic signature from the surrounding landscape, and their discovery with multispectral or hyperspectral sensors is influenced by unique locations of these common signatures. Multispectral and hyperspectral sensors have relatively limited fields of view, and are best suited to small areas of interest, thus are tools well suited to documenting areas of some known record. Surveying broad swaths of the landscape for prehistoric resources will most effectively be accomplished with a sensor that can provide detailed 3D information, or an EO sensor of extremely high resolution, potentially working in tandem with some type of automated detection algorithm.

Creating 3D models or maps of the landscape provides a high resolution perspective on small anomalies that can be analyzed for either prehistoric or historic cultural resources. **Section 1.5** describes how miniaturized EO and LIDAR sensors can be flown on sUAS to collect the data needed to create these 3D maps. These sUAS can be deployed as needed or systematically over areas of the landscape likely to contain resources, or areas that are likely to be disturbed through the impacts of climate change or human activity, like areas of known permafrost subsidence and erosion (rivers or coastlines). Localized short and long-term monitoring of these resources can also be efficiently conducted with sUAS. For example, using sUAS to regularly monitor the 3D movement of graves sites from uplifting or erosion impacts, can aid community decision-makers in the management of these community assets.

The **Cultural and Archaeological Heritage** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.11-D.12, also concluded that,

> *UAVs are also frequently employed to produce high-quality 3D models for preservation, documentation, and management of cultural heritage sites. UAV-borne sensors allow for the acquisition of data at close range, from multiple angles of view, even in largely inaccessible places. Making 3D reconstruction and visualization of large scale and tall cultural relics with photorealistic representation has become easier and quicker with relatively low-cost UAV technology. Many of these 3D models have found their way to geoportals and websites, providing the public an opportunity to "visit" via virtual tours. (Wojciechowska, 2019)*

The key element to sUAS monitoring of cultural resources is the digital elevation model, or digital surface model created by the point cloud of data from either the EO sensor using SfM processing, or from LIDAR data collection. SfM processing of EO data is a cost-effective method for creating these 3D maps, with sUAS solutions available for less than $5000 in start-up costs (**see Appendix A**). LIDAR also provides high resolution data that can be used to create 3D maps for cultural resource identification, but the start-up costs of the sensor, supporting aircraft and required computing power to process these rich data sets may prohibit successful implementation by non-experts. Similar conclusions can be found in the comparison matrix, *Analogous Costs and Parametric and Non-Parametric Cost Estimates for Archaeology (US$)*, contained in the full report, **Appendix D.**
The cultural return on the relatively small investment into the sUAS start-up and maintenance costs is far greater than the cost of these technological solutions.

## Online Tools Comparison

Three tools were included on the Online Tools Matrix and found on the Alaska Department of Natural Resources (AKDNR) and the U.S. Bureau of Land Management websites. One of the AKDNR sites, the Alaska Heritage Resources Survey (AHRS) website is restricted most likely because of the cultural sensitivity of the information to Alaska Native Villages. Given this, it is hard to truly assess the information on this website but it is most likely the most up-to-date information available. The AHRS website is a “data repository with information on over 45,000 reported cultural resources (archaeological sites, buildings, structures, objects or locations, etc.), from prehistoric to modern, and some paleontological sites within the State of Alaska" (ADNR, 2021). A Native Village's Tribal Historic Preservation Officer or a community's Historical Preservation Officer may already have access to this website and know to what extent the physical site is being monitored, needs to be monitored and /or is threatened by climate change.

### 3.2.7. EXTRACTABLE RESOURCE IDENTIFICATION AND MONITORING

***Objectives:*** *Identify extractable resources and monitor extraction operations.*

**Unmanned Aircraft Systems and Comparison Cost Analysis**

Identification of extractable resources is possible using sUAS when employing airborne sensor suites as described in **Section 1.5**. But the use case for implementing a sUAS-based program for extractable resource identification in a rural Alaskan community is unique. In the communities that are planning to or are currently exploiting local extractable resources, they will likely be working with geologists that are collecting and analyzing these data, regardless of source aircraft. Additionally, resource identification surveys do not typically need to be repeated unless there is some notable improvement in the survey technology that would allow for new information to be gathered with additional surveys, thus investing in sUAS technology specifically for resource identification may not provide value to a community. However, employing sUAS to support the identification and monitoring of existing extraction sites and supporting infrastructure can be reasonably supported using straightforward sUAS technology.

The **Extractive Industries** section of **Cost Estimating & Analysis** report, **Appendix D**, pg. D.12, concluded that,

> *UAVs are now being used to map pipelines and the surroundings, identify corrosion and damage, monitor soil movement, and detect hydrocarbon leaks, oil slicks, and theft (Pajares, 2015). Industry has also taken renewed interest in the use of drones in surface and underground mines. Many mines are large and located in remote, mountainous terrain, which makes monitoring by traditional methods challenging. UAVs are now frequently used to map, monitor, and assess mine areas and their surroundings (Xiang, 2019).*
>
> *Perhaps due to the industries' competitive nature, cost data for UAV monitoring of oil and gas infrastructure is largely unavailable. However, the techniques are the same as those used in 'Infrastructure', with additional overlap with 'Flooding' (with respect to DEM mapping) [...]*

Please see the comparison matrix, *Analogous Costs and Non-Parametric Cost Estimates for Stockpile Measurements & Volumetric Compliance: Cost Per Fixed Area Survey*, contained in the full report, **Appendix D.**

In Alaska, there are numerous abandoned and often times undocumented mines throughout the landscape. The Abandoned Mine Lands (AML) program administered by the BLM has identified previously documented abandoned mines as discoverable through deed and literature searches, and provides limited funding to support their reclamation. But many undocumented mines, especially small gold mines, exist throughout the state. Surveying the landscape with a UAS outfitted with either an EO or LIDAR sensor can allow for 3D model creation of the landscape, from which anomalous features such as irregularly located depressions in the ground can indicate an abandoned mine. These areas are often unstable and pose a risk to humans as well as wildlife, thus documenting their locations is valuable. In Unalakleet, known mining sites are not in the immediate proximity to the community and are already documented, but other abandoned mines are likely to exist in adjacent areas that travelled less frequently. Identifying and monitoring abandoned mines for stability using sUAS will support overall human safety regardless of where the mine is located.

Monitoring known mine sites, whether active or inactive, for subsidence or unplanned shifts in stability of tailings or settling ponds, is another ideal use for a sUAS. Using a sUAS outfitted with either a LIDAR or EO sensor, high resolution data sets that can be collected and used to create 3D maps of the targeted mine area. These maps can then be used to compare to either baseline site conditions if working to reclaim a site or to other surveys over the same area to perform change detection studies. When mines are associated with a community, 3D change detection studies are important for stability monitoring of mines and the supporting infrastructure but also for extracted resource volumes, and subsequent valuation calculations. For example, volume estimates for gravel mines can be supported using this same 3D mapping methodology.

Environmental and human health associated with mine sites are ubiquitous concerns regardless of precise mine location. When mines have settling ponds for wastewater or tailings piles for overburden, whether the mine is active or not, there is a potential to negatively impact the health and safety of the environment and nearby communities via the chemicals that can be released from these mine wastes. Hyperspectral sensors carried on sUAS can support highly detailed analyses of the chemicals entering the soil and water systems of a given area due to weathering or as a result of accidental release. Highly specialized sensors that are specific for environmental monitoring, such as in situ water or air samplers, can also support the identification and monitoring of these chemicals. Using sUAS to monitor and track the trajectory of these chemicals can help determine potential impacts to nearby communities immediately and over time. Additionally, by flying a sensor that can provide this level of detail instead of manually collecting soil and water samples, the level of chemical exposure for workers responsible for monitoring these wastes over time is reduced.

Monitoring air and water quality with highly specialized sensors at a mine site is the responsibility of the mine operator and can be facilitated by using sUAS. Identifying contaminants outside of the immediate area of a mine is also a good use for sUAS. However, initiating an air or water quality monitoring program outside the boundaries of a mine using highly specialized equipment like hyperspectral sensors mounted on a sUAS, is not cost effective without long-term funding in place. Similarly, initiating a resource identification program using a sUAS may not be cost effective for small communities in Alaska. Nevertheless, using sUAS to identify previously unknown mines or other type of resource extraction sites and to monitor those sites for stability can be accomplished using a sUAS outfitted with broadly applicable sensors, like EO and LIDAR, which can also be used for many other applications in any given community.

**Online Tools Comparison**

Two tools were identified and included on the Online Tools Matrix. Both are found on the U.S. Geological Survey website and outputs include maps, downloadable data in multiple formats. The records in the database are generally for metallic mineral commodities only but also may include certain high value industrial minerals such as barite and rare earth elements. Common industrial minerals such as sand and gravel, crushed stone, and limestone and energy minerals such as peat, coal, oil and gas are not available through the sites. Though the sites are focused on geological information only, it still may take time to become familiar with the site in order to locate the most relevant information as well as a bit of a bandwidth to download maps and data.

A **shortcoming** of the websites for Alaska Native Villages and other rural communities is that they **do not address common extractable materials**, which often involve excavation activities needing more frequent monitoring, depending on the level of use, because of their potential impact to, local residents, cultural and historical sites, environmentally sensitive areas, including water supplies. Further, the U.S.G.S. sites' information is delayed with regards to metallic mineral commodities; hence, if such activity is taking place close by, **real-time data would not be available for monitoring purposes**.

### 3.2.8. WILDLIFE SURVEYS

***Objectives:*** *Identify current populations and dynamics of wildlife species of concern.*

**Unmanned Aircraft Systems and Comparison Cost Analysis**

Alaska defines a large area of land and coastline with little human development, capable of sustaining diverse wildlife populations that are either migratory or permanent in any given area. Large-scale, remote sensing-based monitoring of wildlife is typically limited to large populations of large animals and habitat delineation. Many of these surveys are conducted using satellite-based data collections and manned aircraft flights for visual observations or basic animal telemetry via radio collared animals. **Section 1.5** identified that UAS-collected data have the resolution to support finer detailed wildlife monitoring surveys, inclusive of much smaller animals due to the high resolution sensors available, and the closer proximity that UAS fly in comparison to manned aircraft or satellites.

EO and infrared sensors are the most common and mature sensors that are carried on a UAS that can be used for various aspects of wildlife and habitat monitoring. EO sensors are intuitive, and if flown systematically can provide detailed information about medium to large animal populations and their dynamics on the landscape. Using EO sensors on sUAS, data can be safely and efficiently collected about migration patterns, reproductive habits, life stage assessments and habitat requirements without direct disturbance to the animal or population. Sensor resolution will still determine the smallest animals that can be accurately monitored using these technologies, and the altitude and type of UAS will dictate how much area the wildlife survey can effectively image. As with other UAS-based systematic surveys, the area that needs to be imaged and the level of detail required to answer the scientific question, will determine the type of aircraft and sensor that is best suited to the job.

Infrared data collected at low altitudes can be used to identify individual animals on the landscape, but identification at the species level of those animals with this technology is not possible. The heat signatures afforded through thermal infrared imaging can reveal an animal's shape, and can support the monitoring of its general activities, but to identify the species of that animal, combining infrared data with EO data or some other species-specific data is required. Infrared is less useful in the marine environment because the signal cannot penetrate the water to identify targets, thus infrared identification of marine animals is limited to when they are at the water surface or have hauled out on to the land. Another limitation to the use of infrared to monitor marine populations is the lack of heat signatures of marine animals themselves, as those signatures are often obscured by layers of fat or feathers used to insulate the animal. These different insulations reduce the contrast between the animal and the background environment, eliminating the sensor capacity to differentiate the two.

Multispectral sensors mounted on a UAS can also support wildlife monitoring, primarily through habitat delineation and qualitative habitat monitoring. Multispectral sensors can be used for general habitat delineation just as an EO sensor can be by combining the red, blue and green spectral channels manually to falsely create the same kind of image captured by an EO sensor or a camera. The other channels of a multispectral sensor, typically near infrared and red edge channels, can also be used to identify hard to discern nuances such as water inundation that may be influencing vegetation health. Using multispectral data to calculate NDVI can also identify the relative plant health of forage species for animals, which in turn be used to determine the capacity of that land to support various populations of animals, which in turn can be used to develop management strategies as appropriate.

The recent development of communication networks that integrate UAS for data transfer have applications for wildlife monitoring in remote locations like Alaska. Traditionally, animals that wear radio collars can only be tracked by equipped biologists walking, driving or flying near enough to the radio-collared animals to pick up the signal transmitted from the collar. This process is time consuming and dangerous as it requires a pilot and a wildlife biologist to survey the landscape “listening” for animals. Outfitting a UAS with the same receiver technology would allow for large areas to be surveyed without putting humans at risk, while simultaneously mapping the precise coordinates of the animal’s location. The development of these communication networks is underway for human-based scenarios, but considerable development remains for this technology to be applied in an operational setting in Alaska.

Regardless of the type of sensor that is being carried for any particular wildlife or habitat survey, harassment of animals by the UAS itself is still a potential problem. The two components to this potential harassment are sight and sound. Different animals have different sensitivities to unmanned aircraft. For example, birds that share the same airspace as a UAS will either ignore, fly away from, or attack nearby UAS depending on their species and general nature; raptors are the most likely to attack sUAS. Animal size may also influence its reaction to a nearby UAS, but so will the animals’ previous exposure to non-native environmental variables, e.g. an animal in a zoo will likely be less sensitive to sUAS activity than an animal on the pristine landscape that has never encountered mechanical sound before. The impacts of UAS sound have just begun to be analyzed for impacts to humans and wildlife, but preliminary studies suggest that the same stand-offs suggested to reduce impacts to animals seeing sUAS are reasonable guidelines for reducing sound impacts to animals as well. In general, staying at least 150 feet away from any animal will reduce the impact of the UAS itself on the animal. The most sensitive of the animals to aircraft, both in terms of sight and sound, are those that are rearing or protecting young, and taking special precautions to avoid these animals is always recommended.

Findings the **Wildlife** section of **Cost Estimating & Analysis** report, **Appendix D**, pgs. D.5-D.7, concluded that,

> *The optimal monitoring method for a given study depends entirely on goals and objectives, species characteristics (e.g., size, diurnal vs. nocturnal, color, etc.), spatial scale, and budget [...]*
>
> *Sensitive or aggressive species, or those in remote habitats, are difficult to monitor with traditional, ground-based methods. In such cases, UAV makes wildlife monitoring, management, and protection possible, and often provides more precise results compared with traditional surveying.*

Please see the two comparison matrices, *Wildlife (Ungulates & Birds) - Analogous Costs and Parametric Cost Estimates for Wildlife Monitoring: Total Costs Per Hectare (US$), and Fish (Salmonids) - Analogous Costs and Non-Parametric & Parametric Cost Estimates for Fish Monitoring: (US$)*, contained in the full report, **Appendix D**.

## Online Tools Comparison

Three tools were included on the Online Tools Matrix and found on the Alaska Department of Fish and Game (AKDF&G) and National Oceanic and Atmospheric Administration (NOAA) web sites. Outputs include a variety of management and harvest reports; refuges, sanctuaries, critical habitat areas and wildlife ranges KLM (Google Earth) files/maps; species-related biological, ecological, and environmental data. Becoming familiar with the data sites may take some time as well as having adequate bandwidth to download the mapping images and GIS layers. Data on species of interest may not be readily available at this time if not targeted for research. How current the subsistence data related to Alaska Native Villages can vary on the AKDF&G site. For example, the most current for Unalakleet is 2006, whereas the most current for Golovin (Chinik Eskimo Community) is 2012. Finding truly localized and real-time data/ information for a particular community and/or location could be challenging.

### 3.2.9. PLANT COMMUNITY MONITORING

***Objectives:*** *Identify current plant composition in NVU region and monitor changes in composition and habit.*

## Unmanned Aircraft Systems and Comparison Cost Analysis

Localized plant composition is changing in Alaska as a result of climate change. Though there are some new invasive plant species along highways and runways, the vast majority of the observed plant community changes are the redistribution of native species to Alaska, and increased shrubification of the tundra. Tundra shrubification is an important indicator of latitudinal climate warming, and a concern as increases in shrubs are balanced by a decrease in herbaceous forage species for common subsistence species like Caribou and Musk Ox. Monitoring these plant community changes is important for understanding the impacts of climate change on subsistence use patterns, including the wildlife reliant upon specific plant species. The sensors most commonly used for vegetation monitoring are EO, infrared and multispectral sensors (**Section 1.5**), all of which have been successfully integrated on to sUAS.

UAS measurements of plants fall into two broad categories, 1) species composition and 2) plant vigor. Plant species identification with UAS is accomplished using high resolution EO cameras or multispectral sensors that have been calibrated with field observations to create a species specific multispectral signature. Though less intuitive and more computationally expensive, **Section 1.5** describes how UAS-mounted LIDAR can also be used to perform plant community composition analyses, which is less about species and more about abundance of plant types. LIDAR is especially valuable for measuring shrub encroachment due to the 3D signature of shrubs being very different than typical sedge and low herbaceous tundra composition. The highly detailed spectral information available form hyperspectral sensors can be used for detailed vegetation analyses including species identification via calibrated spectral signatures, similar to calibrated multispectral analyses, but the cost of the sensor and the complexity of the resulting data is not a cost effective solution for plant community definition and monitoring by a community.

Measurements of plant health, or plant vigor, can be accomplished using direct observations from UAS-mounted sensors, but also through computed indices of plant health. Key to understanding the relation of different plant features to overall plant health is key to the interpretation of sensor data and indices used for describing plant health. Infrared sensors can be used to identify water stress in plants due to higher heat signatures of leaves that are water stressed. EO sensors can identify relative plant health using intuitive variables like browning leaves, or can be used to estimate plant height by using SfM processing techniques. Vegetation biomass estimations can also be accomplished using LIDAR point cloud information or from point cloud data collected with EO sensors and processed with SfM to create high resolution 3D maps of an area. These 3D maps can also be used to discern forest vegetation composition, and potentially tundra composition, though these studies have yet to be performed systematically.

Numerous indices of plant vigor have been developed and adapted by the plant monitoring community that can be measured with sUAS. The most common of these indices is the Normalized Vegetation Difference Index (NDVI) that is used as an indicator of plant community health and seasonal variability. NDVI relates plant biomass to photosynthetic activity, and is often used to ascertain impacts from land-disturbance, including climate change. NDVI is calculated using multispectral data, this highest resolution of which is collected by sUAS with COTS multispectral sensors. When combining high resolution multispectral information with infrared data collected by a sUAS, scientists can also calculate leaf area index (indicates amount of foliage in a plant canopy), leaf chlorophyll content (a proxy for plant photosynthetic activity) and biomass estimations. Hyperspectral sensors are able to measure detailed spectral components used to calculate these indices without fusing the data with data collected from different types of sensors, but are not available on COTS sUAS systems.

In addition, the **Vegetation Monitoring** section of **<u>Cost Estimating & Analysis</u>** report, **Appendix D**, pgs. D.3-D.5, also concluded that,

> *"In the last 20 years UAVs have been successfully utilized to detect, assess, and predict changes to plant communities to support ecological research and conservation objectives [...]*
>
> *On the whole, there is a consensus that UAVs are the more cost-effective option for monitoring vegetation at sites between 10 and 20 hectares (ha) when compared to manned aircraft and satellite data. While hundreds of studies detail UAV use for monitoring plant communities, only a small fraction provide concrete cost data. And to date, only a handful of cost-benefit analyses have been published comparing UAVs to traditional monitoring methods.*

Please see the references and comparison matrix, *Analogous Costs and Parametric Cost Estimates for Monitoring Vegetation: Total Costs Per Hectare (US$)*, contained in the full report, **Appendix D.**

It is clear that monitoring the plant communities of a specific area can support detailed change detection analyses of that area via mapping, regardless of cause. In Unalakleet, the need to monitor plants is directly tied to the changes observed across the landscape as a result of climate change, and the impacts of climate change on subsistence activities. Direct observations with a sUAS outfitted with an EO and infrared sensor flown on a regular basis can support change vegetation detection analyses both seasonally and annually, and provide a general indication of plant health. More detailed information about plant vigor can be created by flying sUAS outfitted with a COTS multispectral sensor, and combining those spectral bands to create the various indices of plant health (e.g. NDVI). These solutions can be achieved at relatively low cost, with minimal post-processing requirements, while using sUAS outfitted with EO, infrared or multispectral sensors that can also be flown in support of other scientific questions.

**Online Tools Comparison**

Three tools were included on the Online Tools Matrix and found on the US Forest Service and University of Alaska Anchorage - Alaska Center for Conservation Science websites. The tools are web reports, raw data and plot mapping. Data tends to be from the last decade or prior to 1990. It does take time to become familiar with the site and locate relevant information. Ability to download reports, maps, and data varies. These sites (their data, maps and reports) could provide a baseline from which communities could monitor local species.

## 3.3. ONLINE TOOLS MATRIX - ADDITIONAL CATEGORIES (PERMAFROST & COLLECTION OF TOOLS)

As mentioned in **Section 2.2, Online Tools Comparison Methodology**, in addition to the nine scientific study areas, two additional categories were captured on the tools matrix - **Permafrost** and **Collections of Tools**. The consensus was that these two categories were important enough to have them as standalone categories.

### 3.3.1. PERMAFROST

Two tools were included under the Permafrost category on the Online Tools Matrix. One is the "*4th National Climate Assessment, Chapter 26: Alaska*" report found on the U.S. Global Change Research Program website. The other is the University of Alaska Fairbanks (UAF) - Community Based Permafrost and Climate Monitoring in Rural Alaska website focused on the tribal communities of the Upper Kuskokwim region. The tools consist of a downloadable report, poster, community survey, and presentation. The information contained on the websites is from the past ten years; downloading is straightforward. Reading through the material may take some time.

### 3.3.2. COLLECTION OF TOOLS

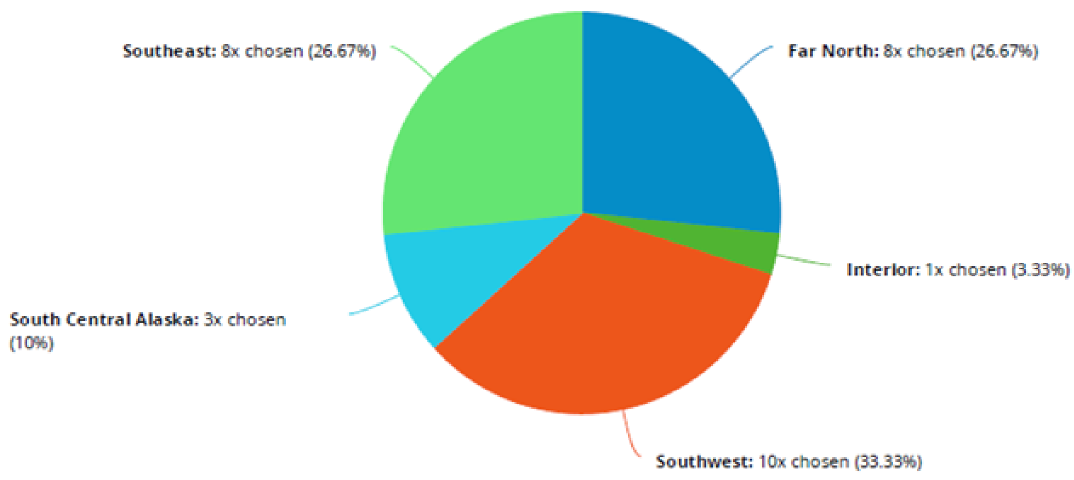
Twelve tools were included under the Collection of Tools category on the Online Tools Matrix. These websites were run by: the University of Alaska Fairbanks (UAF), University of Maine, NOAA, US Geological Survey (USGS), Arctic Landscape Conservation Cooperative (Arctic LCC), Alaska Native Tribal Health Consortium (ANTHC), National Drought Mitigation Center, United States Arctic Research Commission, National Park Service, as well as several joint partnerships. All sites have either or both real-time data or data from the last decade. Several sites include historical data. Five sites have relatively easy data to access. Seven websites will take longer to browse through and find relevant information. Output from the tools includes downloadable datasets and tools in a range of formats, charts, maps, time series, correlation analyses, reports, webinars. Half the sites may take longer to download because of larger MB files or outputs. Another five should be relatively easy to do so. The websites touch on aspects of the nine scientific study areas and climate-related risks. The University of Maine site, Climate Reanalyzer, is a web-based platform for visualizing climate and weather datasets around the globe. Others look at permafrost, vegetation, hydrology, temperature/ precipitation, drought, and climate adaptation and impacts. The USGS - Alaska Science Center provides research on ecosystems, plants, animals, climate, energy and mineral assessments, environmental health, natural hazards, and water resources. The National Park Service - US TEK Literature website provides information on Traditional Ecological Knowledge (TEK). These sites provide a variety of information, which may or may not be community specific.

## 3.4. UNALAKLEET FEASIBILITY STUDY PROJECT SURVEY (APRIL 2020) - RESULTS

As mentioned previously, the April 2020 Survey was sent out to Alaska Tribal Council Chairs and Coordinators, City Council Managers and regional IGAP Coordinators. The survey asked background questions regarding the respondent's region of AK, role in the community, prioritization of the nine scientific study areas, types of data used in decision making, perceived gaps. Additional questions asked about prior experience with UAS (drones) and any additional comments related to UAS and their community, as well as some questions about follow up to the project and interest in that follow up.

Out of those who responded, there was a fairly even breakdown of respondents between Southeast, Far North and Southwest regions. The Interior and South Central regions yielded fewer responses.

**Finding Highlights (31 responses) - Breakdown by Region**




In terms of community roles, respondents often wore multiple hats. The greatest number of respondents identified themselves as:

- Tribal or City Program (General Manager/City Administrator (Dept. Head/Director)
- Associated with a Tribal Non-Profit and/or
- Current Tribal or City Council Member

Others identified themselves as:

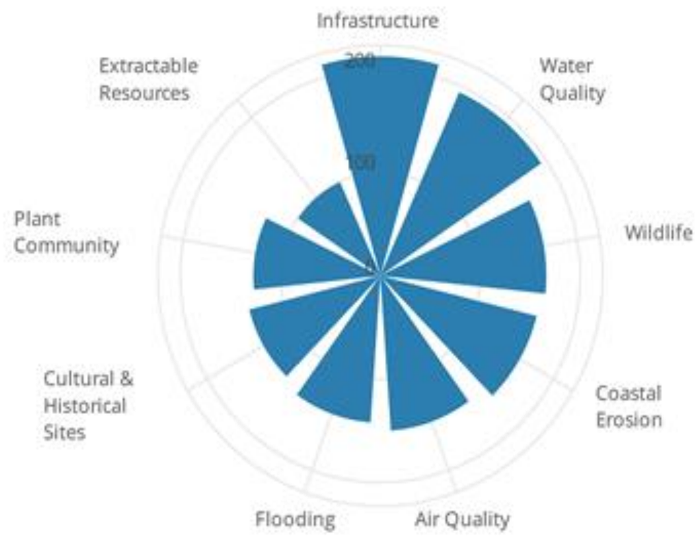
- Tribal or City Program (General Manager/City Administrator (Staff Member)
- Federal, State, Agency or Regional Organization
- Other (City Clerk/Treasurer, City Administrator, Borough Employee)

No respondents identified themselves as:

- Former Tribal Council or City Council Members
- Current or Former Native Corporation Board Member
- Academia
- Elder
- Other Role (e.g. Student, community member, community worker, or other.)

The graphic below illustrates the respondents' prioritization of the nine scientific study areas and how they rank their concerns in relationship to one another.

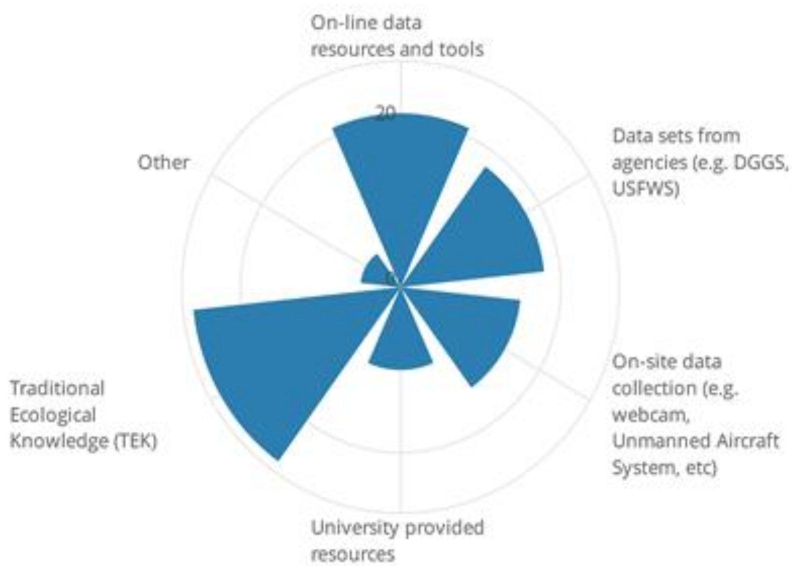
**Ranking of Concerns**




**Other areas of concern resulting from climate change included:**

- Permafrost and impacts to infrastructure
- River temperatures rising, alteration of river flows - river erosion
- Invasive species and algae blooms
- Fish and wildlife diseases
- Food security and community well-being - impacts to subsistence resources and environment
- Increased ocean traffic and inevitable pollution and possible destruction of marine ecology due to loss of sea ice
- Ocean acidification
- Increase in wildfires

**Data Used for Decision Making**



**When asked if people saw a gap in data used for decision making,**

- 2/3rds said, "Yes, they saw a gap"; 1/3rd indicated, "No."

**Survey respondents provided these explanations for gaps in decision making:**

- ***Federal and state government agencies do not work with the native communities here. The data does not overlap and there are data holes*** *throughout the Copper Basin.*
- ***Geospatial data is very informative but in rural Alaska these data are not widely available,*** *for example accurate and precise elevation data can be used to estimate fish habitat and wildfire fuels potential but are not available for the Skagway and Dyea areas in a fine enough resolution to be useful.*
- *More TEK analysis along with other sourced data.*
- *We* ***need more community collected data*** *that is year-round and long term. If data is* ***collected 'closer' to the issue, its use in decision making is more effective. By closer, I mean by community members and guided by Traditional Knowledge. Information is not as effective if it is collected by 'outsiders' and buried in academic online datasets that are difficult to use.***
- *Real time data would be best if available in multispectral and LIDAR elevation data integrated in a single imagery file composed of independent multiple bands. This technology would ensure accuracy in showing actual degradation of permafrost.*
- ***Real-time, in-situ observations coupled by timely and systematic monitoring standards.*** *What I mean is our community in Barrow, which suffers from coastal erosion, flooding and is actively whaling and has other subsistence activities, needs a routine - say annual (ideally 4 times a year) monitoring routine which is conducted according to strict standards (resolution, data standards, etc.) so we can understand what is happening in the community and make long term decisions.*
- *Often there are a dozen organizations to look at when one needs information - BIA, FEMA, Treasury, State of AK, Borough, City, Tribal consortium.*
- *For example, today we need to find power lines buried in some land. The city doesn't have maps. The State has plats but they are old. Reviewing some of them yields some information but not all.*
- ***The gaps are more about missing connections such as how TEK interrelates to established scientific sources.***
- *1. There are no accurate projections of sea level rise for western Alaska. 2. There are no local permafrost projections. 3. Need projections for ice and snow pack, to understand the implications for salmon from shifts from a snowpack based watershed to a rainfall based one.*
- *The gaps may be that all the entities/community members are needing to work together in a respectable manner in order to resolve a common goal/issue that benefits the community as a whole.*
- ***Federal (and state) funding does not match the need.***

- ***Very little localized data on ambient conditions in terms of population ecology / ecological change due to stressors***
- *Traditional Ecological Knowledge is being lost with our elders. Very little or no written documentation of the changes happening in our area.*
- *Lack of funding.*
- *There should be study every year, and for each season.*
- *Need more info on air quality but we are working with the National Park Service to bridge the gap.*
- ***Community-specific scientific data is needed.***
- ***The gaps we tend to see are that we can only do a one-time baseline data collection under EPA's IGAP program.*** *When* ***in reality you need several years of baseline*** *before you can start to see patterns that may be helpful. There* ***is also data mining that happens that the community never sees the results from. The scientific community, either on an agency or college level, does not write into their programs that they will come back and share or give a copy of their research reports back to the communities from where they came.***
- *We're remote enough* ***not many entities decide to come study in our area. Those who do, don't always utilize local experts, so they're often ineffective in their data collection, and results are not very accurate.***
- *The transparency between different agencies and organizations on tying the information to other datasets.*

# 4. DISCUSSION OF RESEARCH QUESTIONS

In **Section 1.2, Research Questions Addressed,** the questions that this Feasibility Study was seeking to answer were described and are summarized here as,

- What are the costs to implement a community-managed, self-sustaining, UAS program?
- How could data collected from UAS and online climate tools contribute to long-term resiliency planning strategies?
- What are the short and long-term cost sharing/partnership opportunities for community managed data collection efforts?
- What are the resilience-related information needs of potential users (e.g. federal and state agencies, Norton Sound Villages, and regional entities) of LiDAR and/or other aerial system-collected data?
- How can we effectively share findings with Tribal Council members and other interested, appropriate parties to determine next steps and long-term project feasibility?

This **Section 4** summarizes the findings through the lens of the above set of research questions.

## 4.1. WHAT ARE THE COSTS TO IMPLEMENT A COMMUNITY-MANAGED, SELF-SUSTAINING, UAS PROGRAM?

UAS are a cost effective solution for monitoring remote Alaska with high resolution sensors in support of informed community decision-making. Though satellite data can be acquired at no cost, managing the data with poor bandwidth in rural Alaska is extremely challenging and requires extensive training that is not available in rural communities. Similarly, data collected by commercial vendors using manned aircraft can cost from $6,000 to $50,000 per collection, which is not sustainable for long-term climate change monitoring in small rural communities. Conversely, data collection with UAS can be accomplished locally and at comparatively low costs if utilizing COTS solutions that can support climate change monitoring.

The immediate costs to implementing a UAS program in a rural community include the **initial investment** into UAS hardware (aircraft and sensor payload) and the hardware and software needed for processing the data into informational tools decision-makers can use. These costs can range from $1,000 to $50,000 depending on the complexity of the sensor and the required supporting software (see **Appendix A**). Reasonably costed UAS solutions in the $5,000 to $20,000 range can provide rich data sets that can be collected and analyzed systematically by local UAS operators to monitor the impacts of climate change on any number of environmental compartments. Computers that can manage the voluminous data collected by UAS are also the ones that are well suited for performing geospatial processing. Typically these computers are powerful laptops that range in cost from $1500-$2500 without operational software programs. The post-processing software that runs on these computers is similar to the UAS solutions in that they can be simple and inexpensive, or complex and more expensive. Initial software costs include purchasing the software, purchasing the license to operate that software, and upgrading when new versions are released. These costs can range from $500 up to $6000 for basic functionality, and much higher for specialized functions.

UAS pilot training is key to launching a successful UAS program, and includes preparation for Part 107 certification testing. The **Part 107 certification** from the FAA is the minimal amount of licensing required to fly sUAS commercially. Part 107 test preparation and certification ensures pilots are familiar with airspace restrictions, legal requirements for safe UAS flights, and atmospheric variables that can impact UAS operations. UAS pilot training to successfully pass the Part 107 exam is extremely variable from $0 if a pilot is able to identify the materials and prepare on their own up to $10,000+ to hire a trainer to come on-site and prepare new pilots for the certification exam. The cost to sit for the Part 107 exam is currently $160 when testing through an FAA test center. Once certified for flight by the FAA, **hands-on UAS flight training** is critical for UAS pilots to become familiar with the equipment they will be using to perform data collection for decision-makers. Practicing basic flight planning, performing test flights under variable conditions, and managing the collected data is critical for operational success in the long-term. When basic UAS operations become second nature due to practice, more energy can be devoted by the UAS pilots and observers to creating systematic data collection flight plans, and collecting high quality data that can be used for decision-making.

Successful data collection is key for creating quality informational products with geospatial processing software. Also key is **software training** for pilots and observers on how to use the geospatial post-processing software that supports the sensor, and the use of different data processing protocols to create different kinds of informational products. Training with geospatial processing software can be extensive, expensive and time-consuming if pursued through a university. However, when purchasing UAS data processing software, often there will be offered either a free training class or online tutorial to ensure proper software use and streamlined procedures. It is important to note that a basic understanding of computer operations, file structure and online interfacing is required to be a successful UAS pilot. Depending on the complexity of the monitoring program, the cost of training pilots to create the high quality informational products for decision-makers will fluctuate.

Once preliminary training has been completed, and the Part 107 certification acquired, **UAS hardware and software maintenance costs** will remain. These costs include purchasing spare parts like propellers and batteries, having periodic maintenance performed by the factory and upgrading communications components, but also include the costs to maintain the supporting geospatial processing software licensing through time. Additionally, the Part 107 pilot certification is only valid for two years, and the cost to retake the exam is the same $160 fee for renewal as it is for establishment. Costs for electricity and internet access are required for UAS flight planning and data management, and are not insignificant in rural communities. These costs vary broadly, as does the bandwidth available to support UAS operations and FAA permission requests and reporting requirements. It must be understood that program costs include all of those listed, but also the cost of the **pilot salaries** to participate in the training programs, perform test and data collection flights, process UAS-collected data into informational products, and deliver those products to decision-makers.

Establishing a UAS-based monitoring program in rural communities is less expensive than performing regularly scheduled, contracted, manned aerial surveys over a community. For example if the requirement is a single data collection flight, like performing an extractable resource exploration, contracting a single collection for approximately $50,000 may be most appropriate. But to monitor localized impacts of climate change, documenting coastal erosion processes, prepare for flooding, perform search and rescue techniques and inspect infrastructure, on both a regular and ad hoc basis, then a UAS program is a cost effective solution.

### 4.1.1. UAS OPERATIONAL CONSIDERATIONS

**UAS Legal Requirements:** UAS pilots can fly as hobbyists, commercial operators or government operators. Each of these designations have different requirements to legally fly, but to fly for commercial gain, UAS pilots need to be certified by the FAA under the Part 107 rule.

**Insurance:** Hull insurance and liability insurance can be acquired by Part 107 certified pilots for little cost for recreational flying, but for commercial ventures, additional flight insurance should be acquired by the UAS pilot. During contractual discussions, additional insurance or indemnification clauses may become relevant depending on the size, the target, and the duration of the mission.

**Sensor Selection:** The accuracy of any data products are a direct reflection of the quality of the sensor used to collect the imagery. If lower quality sensors are used to collect imagery of an area, the resulting maps and data products will have a greater amount of uncertainty associated with the data. This may not be a problem for casual observations of a given environment. However, if long-term change detection monitoring efforts are the goal, high quality data and metadata will be required to create the cm-scale accurate map products. Considering the objective of the data collection effort is important in determining the appropriate sensor and supporting aircraft to use for environmental surveys. For rural communities with limited resources, selecting a UAS that is easy to operate, outfitted with reasonably high resolution sensors that can be used to support multiple missions is a cost effective solution for program implementation.

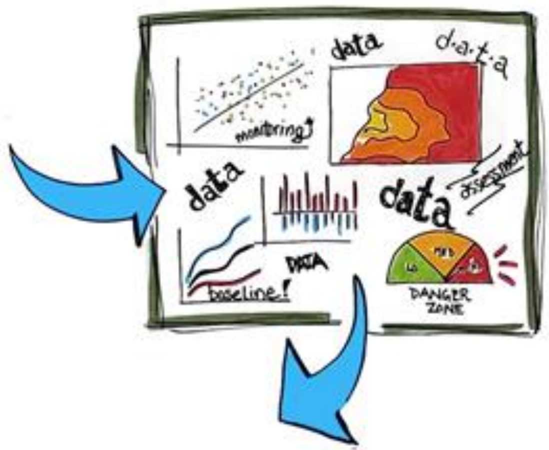
**Flight Conditions:** Variables and thresholds for flight are important considerations for the collection of repeatable data. Being able to perform sUAS flights regularly allows for the development of a sUAS flight conditions database of how the vehicle as well as the sensor payload performs under specific environmental conditions. This database of parameters can then be used to develop threshold conditions for flight incorporating targets, seasonality, temperature, wind speed, humidity, potential for precipitation, and cloud cover. Though some reliance on local forecasting will always be an uncontrolled flight variable, defining the optimum ranges of flight conditions will increase efficiencies and reduce error.

## 4.2. HOW COULD DATA COLLECTED FROM UAS AND ONLINE CLIMATE TOOLS CONTRIBUTE TO LONG-TERM RESILIENCY PLANNING STRATEGIES?

### 4.2.1. ADDRESSING GAPS IN DECISION MAKING IDENTIFIED IN THE APRIL 2020 SURVEY

As outlined above in **Section 3.4. Unalakleet Feasibility Study Project Survey (April 2020) - Results**, the April 2020 Survey asked the following three questions related to **Decision Making**:

1) Of the nine concerns listed above [Coastal Erosion, Flooding, Infrastructure, Water Quality, Cultural & Historical Sites, Plant Community, Wildlife, Air Quality, and Extractable Resources], what data does your community use to make decisions about these concerns? Please check all that apply.
2) Do you see gaps in the data resources used for decision-making?
3) If yes, please briefly explain the gaps that you see.



visual synthesis by anne@TheDoodleBiz.com

Survey respondents answered that they relied heavily on "Traditional Ecological Knowledge (TEK)" followed by "On-line data resources and tools" and then "Data sets from agencies (e.g. DGGS, USFWS)". Less used data resources, possibly because of availability and lack of training and/or resources, were "On-site data collection (e.g. webcam, Unmanned Aircraft System, etc.)" and "University provided resources". Furthermore, two-thirds of respondents indicated that they saw a gap in data used for decision making.

The explanations for the perceived gaps are listed in **Section 3.4**. Below summarizes what these results might mean to the research question, "***How could data collected from UAS and online climate tools contribute to long-term resiliency planning strategies?***"

Related to a UAS program, respondents expressed that, "If data is collected 'closer' to the issue, its use in decision making is more effective." Collection of data by community members, guided by Traditional Ecological Knowledge (TEK) is critical. Information collected by "outsiders," often "buried in academic datasets…" were seen as difficult to use and not as effective. Further not drawing on local expertise and TEK during the data collection process would lead to inaccurate results.

As seen in the survey answers, the majority of respondents indicated that TEK is used during the decision making process. TEK can help determine data that would be critical to collect. By working with elders and other community members knowledgeable about local conditions and changes, a community can work to establish its own baseline, integrating TEK with UAS data collection, which would then result in the collection of community-specific scientific data. Respondents also indicated that ongoing monitoring, at least annually, if not more frequently, was critical and that it should (strictly) adhere to monitor standards (e.g. resolution, data standards, etc.). Establishing such a baseline, with guidance from TEK, coupled with an ongoing monitoring program would help to develop long-term resiliency planning strategies and decision making.

In terms of online climate tools, survey respondents saw the tools difficult to use and less applicable to their communities. There are holes in the data and, since often collected by "outsiders," not as accurate. There is also a lack of integration with local TEK. Because a UAS program is expensive to start and maintain, communities, unable to make the investment or develop a regional partnership, will continue to use online tools and other climate data resources to develop long-term strategies if they are seeking scientific date to use in conjunction with TEK. --- Online climate tools may not meet all of community's needs but would provide broader regional climate data and projections at an acceptable cost.

### 4.2.2. UAS AND ONLINE TOOLS DATA APPLICATION INTO ADAPTATION PLANNING AND DECISION MAKING

The gathering, analysis, and application of UAS-sourced data offers significant added value to planning and decision making for both public and private users. One of the main values of UAS data is improving the quality of data available for analysis, planning, and management decisions. It offers access to more locally specific information at a reasonable cost. It engages more local people to do the drone work, thus adding to the local knowledge base the understanding and interpretation of the data. It builds local technical capacity and economic activity. It also provides an ongoing method of local monitoring to track the results of actions taken over time and inform adaptive management decisions into the future. In short, drones can provide better data that is technically sound and locally sourced, thus leading to better decision making. From better decisions come greater health and resilience for the communities and natural resources of Alaska.

On the other hand, data gathered from online climate tools, as collected and organized under the 9 scientific study areas in the **Online Tools Comparison Matrix (Tools Matrix) (Appendix B),** is also relevant to the adaptation and decision making process. If a UAS program is too costly to set up and/or one is being phased in, then such tools can provide basic background (historical and/or projected) data/information, which can complement Traditional Ecological Knowledge. Further, if a UAS program does exist, these online tools could support a UAS program and the decision making process by providing basic (historic and projected) background information, allowing the UAS program to establish a current baseline and undertake ongoing monitoring.

## UAS Data Integration into Local, State, and Federal Plans and Reports

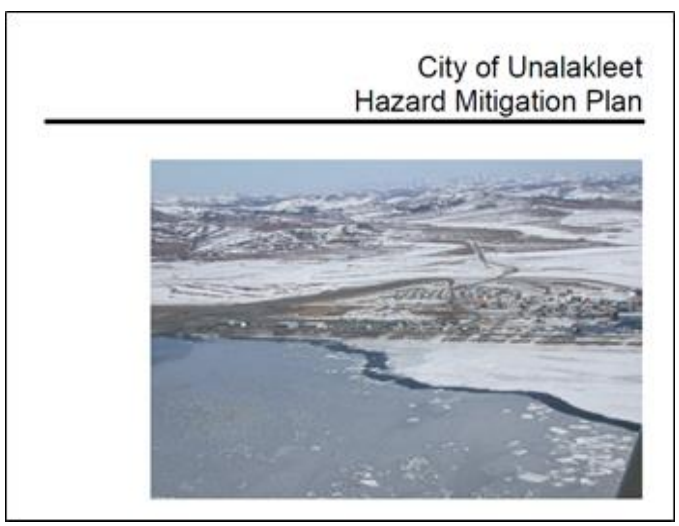
There are many opportunities to integrate drone data into all levels of plans, research studies, documents, and reports. A few planning examples include: Hazard Mitigation Plan (HMP); Local Economic Development Plan (LEDP); Small Community Emergency Response Plans (SCERP); Climate Adaptation Plan; Comprehensive or Master Land Use Plan; Natural Resource Management Plan; Transportation Plan; Housing Authority Plan; Coastal Management or Restoration Plan, and many more. Please note these plans are examples of possible plans that a community, region or other entity might have. Not all documents are discussed in this study.

The UAS feasibility study reviewed selected plans and reports at four scales (local, regional, state, and federal) to identify potential integration points for drone data and how it may apply to planning and decision making processes. The following plans and reports were reviewed. Their relevance for integration and application is outlined in the **Integration/Adaptation of Data into Planning Matrix** (**Appendix C**). The checklist indicated significant relevance in these documents to the nine scientific study areas using a rating of 3 (highest) to 1 (lowest). A review of these documents is summarized below as examples of useful applications relevant to all jurisdictions and organizations.

1. City of Unalakleet Hazard Mitigation Plan 2015
2. Unalakleet Local Economic Development Plan (2014-2019)
3. Unalakleet Small Community Emergency Response Plan (SCERP)
4. Bering Strait: Marine Life and Subsistence Use Data Synthesis (2014)
5. 2015 Alaska Wildlife Action Plan
6. Fourth National Climate Assessment: Alaska (Chapter 26)

### Hazard Mitigation Plans (HMP)

(City of Unalakleet, 2015)

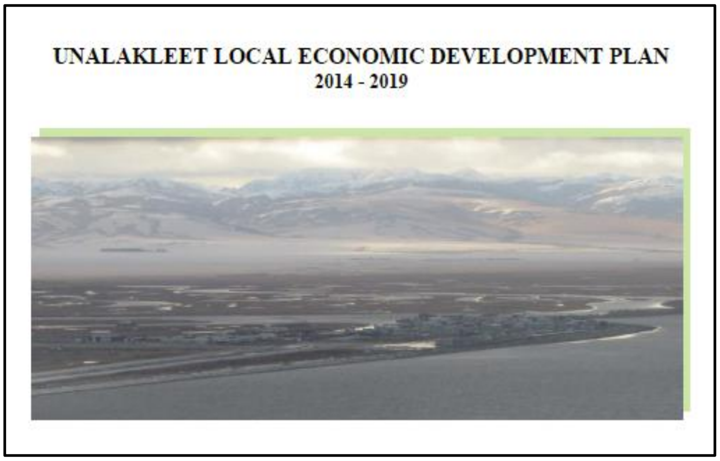



At the local level, hazard mitigation planning and implementation actions are well suited to integrating drone data. HMPs are designed to identify and characterize risks and recommend hazard mitigation strategies that reduce risk and protect people, property, and natural systems. This involves the process of identifying, screening, and profiling specific hazards for local communities. Drone data can be particularly helpful in this landscape analytical process. Drone data can help identify spatial and surface anomalies to detect risk factors, recognize safety gaps, and monitor results of mitigation and restoration efforts. HMPs are also updated on a regular FEMA 5-year cycle making them valuable for tracking monitoring data and adaptive management results for hazard mitigation over time. HMPs are also particularly important because of their role in FEMA grant eligibility factors. The use of drone data could improve the detection of climate change and other risk factors for inclusion in hazard planning and subsequent FEMA funding for pre-disaster mitigation or post-disaster recovery. This could lead to improved grant eligibility and more competitive grant proposals of all types.

The review of the City of Unalakleet HMP indicated particular relevance to data related to coastal and river erosion, flooding, severe weather, and wildland/tundra fire. In the Unalakleet example, drone data for the next HMP update could include the following useful drone data analysis: 1) understanding coastal erosion with base flood elevation data; 2) improving flood preparations with digital elevation models; 3) enhancing risk analysis for infrastructure using maps of high risk facilities; 4) taking air and water quality samples for public health risk assessment; and 5) cultural and historical site risk analysis. It was also noted that other potential applications for drone data included monitoring and evaluation, utilizing traditional ecological knowledge, and sharing data on the LEO Network.

Overall benefits to UAS integration for hazard mitigation plans include improvements for: 1) Grant eligibility and funding; 2) Data quality; 3) Filling local data gaps; 4) Risk characterization and prioritization; and 5) Monitoring and evaluation over time with regular updates.

### Local Economic Development Plans (LEDP) (Kawerak, 2013)




Communities around Alaska and in the Lower 48 often develop a local economic development plan to determine a community's values, goals, objectives and strategies in order to guide future growth and economic development on a somewhat regular basis. As an example, the Unalakleet Local Economic Development Plan 2014-2019 (LEDP) is a joint effort to do just that between the Native Village of Unalakleet, City of Unalakleet, and Unalakleet Native Corporation, with assistance from the Kawerak Community Planning and Development Program staff.

Localized UAS data collection and analysis are relevant and critical, to the local economic development planning program for not only establishing a baseline of relevant data but ongoing monitoring. Specifically, in the case of the Unalakleet LEDP, such data could provide critical background information for Chapters 3.0 Community Description and Subchapter 3.4 Community Infrastructure, 5.0 Environmental Scan, and 9.0 Development Priorities and Implementation.

In the Unalakleet 2014-2019 LEDP, the Top Priorities were:

1. Construct New Water Line
2. Roads for Both Sub-divisions
3. Elders Assisted Living Facility
4. SAR and Fire Department Funding
5. Continued Monitoring of Contaminated Sites
6. More Homes for Families
7. Sub-regional Clinic Fully Staffed
8. Crab Processing/Holding/Value-added Seafood Facility
9. Replace Boat Ramps
10. Evacuation Center

Out of the nine scientific study areas, those with the highest relevancy to the LEDP Top Priorities and cultural values would be Coastal Erosion, Flooding, Infrastructure, Water Quality, Wildlife, Plant Community, Cultural and Historical, and Extractable Resources. The one scientific study area with less relevance to the LEDP would be Air Quality.

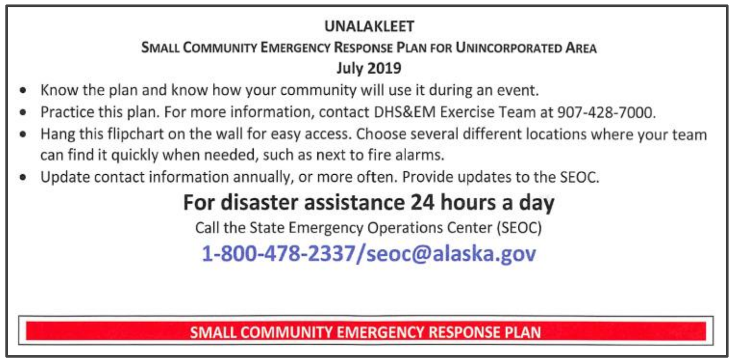
The LEDP is structured in such a way to (Kawerak, 2013):

- Provide the community with a **complete inventory of existing**..., and **public and private facilities**;
- Equip the community with the basic informational tools of local planning that accurately show land status and ownership as well as **traditional resources and subsistence areas**;
- Provide implementation strategies for development priorities including **land use, public facilities** and services, **capital improvements**, economic development and community governance;
- Place emphasis on the crucial development issues: economic and resource development, land use planning and needs of the community **with regards to infrastructure, and priority capital improvement projects**;
- Involve key decision makers to assist in the identification of common goals and direction to achieve those goals.

A UAS data collection and analysis program would help to provide critical information to decision makers during the development process.

Finally, development of a localized UAS program can be an economic strategy of its own. Not only could it provide a critical data collection service to other neighboring communities and regional, state and federal agencies but also it could also be a tremendous asset to local and regional Search and Rescue (SAR) Teams and potentially fire departments.

### **Small Community Emergency Response Plans (SCERP)** (ADHSEM, 2021)



UNALAKLEET

SMALL COMMUNITY EMERGENCY RESPONSE PLAN FOR UNINCORPORATED AREA

July 2019

- Know the plan and know how your community will use it during an event.
- Practice this plan. For more information, contact DHS&EM Exercise Team at 907-428-7000.
- Hang this flipchart on the wall for easy access. Choose several different locations where your team can find it quickly when needed, such as next to fire alarms.
- Update contact information annually, or more often. Provide updates to the SEOC.

**For disaster assistance 24 hours a day**

Call the State Emergency Operations Center (SEOC)

1-800-478-2337/seoc@alaska.gov

SMALL COMMUNITY EMERGENCY RESPONSE PLAN

"*Successful management of a disaster begins at the local level. When a community is prepared to deal with a disaster, the impact can be minimized and lives may be saved. One key to community preparedness is a community emergency plan that defines how the community will manage disasters. The plan should include local, regional, and state resources that support local response.*"

The State of Alaska developed the SCERP as an approach to emergency management for small communities with a population of 2,000 or less. The SCERP, put together by a local Community Planning Team, is a customized flip book with essential, community-specific information for responding to a disaster. Through such planning (and disaster response exercises), it provides those on the ground a course of action to immediately respond to a local disaster and coordinate with outside emergency response agencies such as the Alaska Division of Homeland Security & Emergency Management and the State Emergency Operations Center (SEOC).

A sUAS program fits well into the "Damage Assessment" component of the SCERP and could also support "technical" assessments. During the Damage Assessment process local governments are responsible for providing an initial incident size-up to the borough or State Emergency Operations Center (SEOC). An incident assessment report within 24 to 48 hours helps to determine the required level of borough/state assistance and need for a disaster declaration.

Generally speaking, there are three types of damage assessments (ADHSEM, 2017):

- Rapid Assessment or "windshield survey"
- Initial Damage Assessment
- Preliminary Damage Assessment

"Technical" assessments may need greater technical expertise, not available locally, but a sUAS program could provide initial critical data, including imagery, to experts, helping them better prepare for an onsite visit to a remote location.

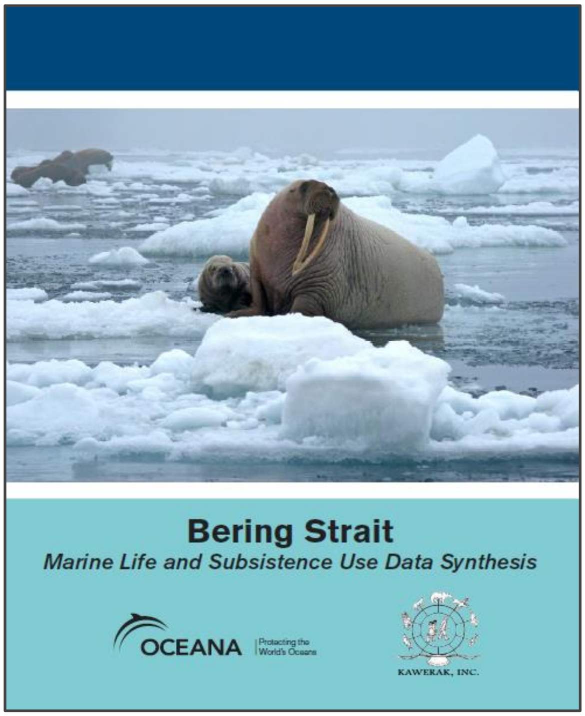
Specific sections of the SCERP where a sUAS program could fit in are:

- The First 4 Hours - Take immediate action (Begin Search and Rescue (SAR) as necessary.
- The First 12 Hours - Prepare transportation routes (Assess road and transportation conditions.
- The First 24 Hours - Assess situation and resources needs; Gather damage information.
- Through 48 Hours - Assess/report damages.
- Beyond 72 Hours - Assess damages and manage debris.
- Sheltering and Evacuation - Ensure ability to return safely.
- Evacuation
- Damage Assessment and Resource Requests

The most relevant use of a sUAS program during Damage and "technical" Assessments of an incident would be to: 1) Aid in search and rescue, and recovery missions; and 2) Conduct a size-up of environmental and critical infrastructure damage. Hence, out of the nine scientific study areas, those with the highest relevancy (3) to the SCERP process and life safety efforts would be related to Coastal Erosion, Flooding, Infrastructure, and potentially Water Quality. The next level of relevancy (2) would conceivably be Air Quality (as related to forest fire or chemical fire), Extractable Resources (if the resources were potentially hazardous), Wildlife and/or Plant Community (for reasons of subsistence). Finally, though important overall, the Cultural and Historical study areas would be least relevant (1) in terms of disaster at least initially.

### **Bering Strait: Marine Life and Subsistence Use Data Synthesis (2014)** (Oceana & Kawerak, 2014)

At the regional scale, this in-depth book-length report provides a synthesis and overview of the marine species and ecosystems of the Bering Strait region. From the report: "The goal of this data synthesis is to assist policymakers, including tribal governments in the region, in making informed decisions..... Many important management and policy decisions affecting the Bering Strait region will be made in the next few years, and decision-makers must engage the tribes of the region. Tribes have a legal right to government-to-government consultation, and tribal members have traditional ecological knowledge that is relevant for decision-making" (Oceana & Kawerak, 2014).



Oceana, Inc. and Kawerak, Inc. collaborated to gather, analyze, and present a seasonal synthesis of information and maps for sea ice, subsistence resources, and marine species concentration areas. They used data drawn from both traditional ecological knowledge (TEK) and Western science for location, abundance, and health of subsistence resources, marine species, and marine ecosystems. The review of subsistence resources is drawn mainly from 9 coastal Alaska Native Villages in the region. It also reviews marine species populations and marine ecosystems, including marine mammals, seabirds, fish, zooplankton, seafloor life, sea ice, and ecosystem analysis.

UAS data offers a number of opportunities to enhance the use of the information in this report. The mix of TEK and science data can provide context to help interpret UAS findings and for integrating UAS data into decision making processes. UAS data can also help address some of the data gaps identified in the report. The authors noted that overall data for subsistence use in the Bering Strait region was patchy and often old. (p.135) They also identified data gaps where UAS might be helpful, such as: 1) lack of nearshore data on seasonal sea ice conditions and flood events; 2) water samples to map zooplankton distribution patterns; 3) long term monitoring of Important Ecological Areas for management decision support; 4) observations for fishing compliance and impacts of industrial activities, and 5) assessing trends for river freeze-up or break-up conditions and timing. These and other UAS uses could improve predictability, safety, and success rate for hunting and fishing seasons. It can also provide a mechanism to improve local tribal engagement and comply with mandatory consultation with the tribes for decisions affecting tribal resources. This report has relevance to all 9 of the scientific study areas, especially for areas of wildlife, air and water quality, coastal erosion, cultural practices, and extraction industries.

Overall benefits to integration of local UAS data into regional wildlife and ecosystem reports, such as the Bering Strait report, would include improvements for: 1) local tribal engagement in decision making; 2) more data for local and nearshore ice and ecological conditions; 3) more accurate assessment of risks from commercial and industrial activities; 4) improved understanding and management of subsistence resources; 5) increase safety and harvesting successful for hunting and fishing; 6) increased technical capacity at community level; and 7) improved collaboration across local, state, regional, and federal jurisdictions.

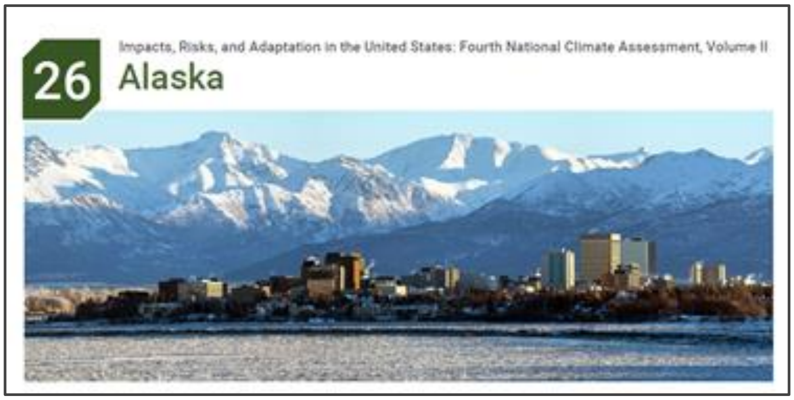
### State Wildlife Action Plan (SWAT) (ADFG, 2015)

At the state scale, the 2015 Alaska Wildlife Action Plan is meant to guide management of fish and wildlife species and their habitats to prevent listings under the Endangered Species Action. As such, it has direct relevance to the study and management of wildlife and habitat that serve as critical subsistence resources for Alaska Native Villages. Drone data is especially useful in studying wildlife species and habitat areas, providing visual data for remote landscapes and waterways that otherwise could not be evaluated. The ability to visualize and map wildlife areas and identify specific hazards to threatened or endangered species can increase the effectiveness of conservation programs. These state wildlife reports are updated every 10 years, providing a long term monitoring opportunity when using consistent UAS data over time.


The 2015 Alaska Wildlife Action Plan contains a complete review of Alaska wildlife, habitat conditions and trends, threats, and conservation needs. There is potential to improve this report with additional UAS data. Indeed the report itself declares that "A high priority conservation action in Alaska is data acquisition". Local cities and Native Villages can use UAS to contribute high quality, time sensitive and locally specific data for the wildlife assessment, planning, and conservation management process. The knowledge gained through cooperative UAS data gathering can generate a synergy between the state's interest in species protection and Native Village needs for subsistence resources. By engaging local villages in gathering UAS data, the information can be combined with the local traditional knowledge to give a deeper understanding to the changes observed in species and habitat conditions. Drone monitoring at regular intervals during the 10-year update cycle could establish trends early, inform conservation responses, and increase conservation success overall. Wildlife action plans are relevant to all nine of the scientific study areas.

Overall benefits to integration of local UAS data for state and local wildlife action plans include improvements for: 1) more local observation data for wildlife and habitat; 2) added understanding of traditional knowledge; 3) access to observe remote wildlife and fishery areas; 4) enhanced subsistence resource management; 5) better wildlife management and conservation; and 6) improved federal compliance for threatened or endangered species.

### Fourth National Climate Assessment (NCA4): Alaska Chapter 26 (Markon et al., 2018)




At the federal scale, the most comprehensive national report on climate change issues is the National Climate Assessment. Now in its Fourth Edition (NCA4 2018), this report provides in-depth climate change information organized by topic and by geographic region. In NCA4

Chapter 26 is devoted to the state of Alaska. There is also a chapter on Indigenous Populations and many other topic chapters with relevance to Alaska's changing climate conditions. The report is updated every 3-5 years with the opportunity for individuals and organizations with relevant and verifiable data to respond to the call for nominations for authors and technical input.

The NCA4 Alaska Chapter offers analysis on 6 key topics where UAS data gathering and analysis could improve the overall understanding of Alaska conditions, risks, and potential adaptive solutions. The key message topics are: 1) Marine Ecosystems; 2) Terrestrial Processes; 3) Human Health; 4) Indigenous Peoples; 5) Economic Costs; and 6) Adaptation. These topics outline the impacts and needs regarding rapidly warming conditions, the loss of Arctic sea ice, ocean acidification, thawing permafrost, and increased flooding and erosion, among others. Understanding these changes at the local level could be improved through UAS data and analysis. The resulting negative impacts to infrastructure, human health, wildlife habitat, nutrition, food, water and subsistence resources, and overall community well-being could be addressed more effectively with improved local data on the underlying terrestrial and aquatic changes taking place across the lands and waters.

Overall benefits of integrating local UAS data into national reports, such as the next National Climate Assessment, would include improvements for: 1) more local community engagement, 2) more relevance for local conditions; 3) more accurate local risk assessment and effective adaptation strategy development; 4) improved understanding and management of subsistence resources; 5) increased technical capacity at community level; and 6) improved collaboration across local, state, and federal jurisdictions. The next edition, NCA5, issued a call for nominations for authors and technical input. Alaska contributions, including local UAS information, would be a valuable addition to the drafting of the next report.

## Summary

The integration and application of UAS data into planning and decision making processes can be a valuable upgrade in quality and effectiveness at local, state, and federal levels. There are benefits to the quality and completeness of visual and scientific data available, improved collaborative process outcomes, and overall more effective risk assessment and adaptive strategy development. There are also many ready opportunities for local UAS contributions to consistent, long term monitoring and timely adaptive management responses to improve health, safety, and welfare outcomes.

Protocols for UAS flight operations during emergency response activities are not well established outside of the USCG Arctic and Western Alaska Area Contingency Plan, be they for observing flooding events or other small and large-scale disasters (Murphy et al., 2017; Thamm et al., 2013). An important next step should include the establishment of sUAS flight protocols for emergency response. Using defined protocols will allow for the creation of consistent visualizations that can be used by a wide variety of decision-makers will increase the saliency of sUAS collected data for efficient decision-making. Such sUAS flight protocols are being developed as part of an ensuing Unalakleet project, *Remote Unmanned Aircraft System (UAS) Inspection and Response Team Development in the Bering Strait Region,* funded by the Arctic Domain Awareness Center (ADAC), a U.S. Department of Homeland Security Center of Excellence hosted through the University of Alaska.

Physical and cultural communication challenges play a significant role in disseminating information for local decision-making in rural Alaska (Kontar et al., 2015). These communication challenges are especially pronounced during emergency situations and when the sparse communication infrastructure across rural Alaska is damaged in an event. Developing localized communication strategies that include UAS reconnaissance during emergencies, and communication pathways out of rural Alaska to hub communities where resources can be deployed, is an important aspect of a holistic rural UAS program that can determine its success locally and regionally.

## Online Climate Tools Data Integration into Local, State, and Federal Plans and Reports

The following section discusses opportunities where the **Online Tools Comparison Matrix (Tools Matrix) (Appendix B)** could assist in the planning process whether or not a UAS program were developed. These six plans are the same six plans discussed in the above Section, 4.2.2. UAS Data Application into Adaptation Planning and Decision Making. Again, the first three plans, local plans, are from Unalakleet's planning process. They are used for discussion purposes; such plans are common for many Alaska communities. The last three represent plans at the regional, state, and national levels.

### City of Unalakleet Hazard Mitigation Plan 2015

In the City of Unalakleet Hazard Mitigation Plan 2015, the websites found in the Tools Matrix under the 9 scientific study areas could provide the initial background information under Chapter 5. Hazard Analysis. Additionally, the Tools Matrix could provide background information under Chapter 6. Vulnerability Assessment, especially under 6.2 Land Use and Development Trends (6.2.1 Land Use and 6.2.2 Cultural Sites) as well as 6.3 Current Asset Exposure Analysis (6.3.1 Asset Inventory).

Specifically, websites found in the Tools Matrix under the Coastal Erosion, Flood Preparation, Infrastructure, Cultural & Historical Site study areas, plus Collection of Tools category could provide key maps and data. Though currently available only to a handful of communities, the Alaska Division of Geological & Geophysical Surveys (AKDGGS) - Western AK Flood Inundation Maps website (https://dggs.alaska.gov/pubs/id/29719) provides detailed color-indexed elevation maps for flood-vulnerable coastal communities in western Alaska. Finally two U.S. Energy Information Administration sites found under Infrastructure may also be of interest and useful (https://www.eia.gov/special/disruptions/ and https://www.eia.gov/state/?sid=AK).

### Unalakleet Local Economic Development Plan (2014-2019)

In the Unalakleet Local Economic Development Plan (2014-2019), the Tools Matrix could be very helpful in providing basic background information under Chapter 5.0 Environmental Scan, especially related to 5.3 Climate and potential climate risks, but also 5.2 Vegetation, 5.4 Wildlife, 5.5 Historic Preservation, and 5.6 Seismic, Flood, and Wetlands Information. The Tools Matrix includes websites that could be useful for each of these sections under the related scientific study area.

### Small Community Emergency Response Plans (SCERP)

The Tools Matrix does have potential relevance to Small Community Response Plans. SCERP, as the name suggests, is a community's tool for immediate emergency responses. Websites that would be helpful are those that provide real-time data for weather (e.g. temperature, barometric pressure, and wind) but also storm surge. NOAA's Tides and Currents website (e.g. for Unalakleet - https://tidesandcurrents.noaa.gov/stationhome.html?id=9468333) could provide important monitoring during the time period of the incident in order to make sure emergency responders are adequately prepared. The caveat being that your community would have to have a NOAA monitoring station. Another site for monitoring is the National Weather Services (NWS) Alaska Sea Ice Program (ASIP) (https://www.weather.gov/afc/ice).

The primary objective for monitoring such sites is to ensure communities are prepared for changing conditions and that information is conveyed to response teams. Hence, it would be good to have such resources contained in the "If You Have Advance Warning - Take Precautionary Measures" and/or "The First 4 Hours - Begin Response" sections and be sure to monitor on an ongoing basis.

### Bering Strait: Marine Life and Subsistence Use Data Synthesis (2014)

In the Bering Strait: Marine Life and Subsistence Use Data Synthesis (2014), two of the three websites found on the Tools Matrix under Wildlife Surveys are potentially the most relevant. These websites are hosted by the Alaska Department of Fish and Game and NOAA, (http://www.adfg.alaska.gov/index.cfm?adfg=maps.refugeboundaries&disclaimer=read) and (https://www.fisheries.noaa.gov/alaska/science-data/alaska-fisheries-science-center-surveys-arctic-2019-preliminary-findings). Another site that may be of assistance is the National Weather Services (NWS) Alaska Sea Ice Program (ASIP) (https://www.weather.gov/afc/ice).

### State Wildlife Action Plan (SWAT)

In the 2015 Alaska Wildlife Action Plan, websites found on the Tools Matrix could be helpful in providing basic background information under a number of the chapters such as Alaska Overview, Species of Greatest Conservation Need, Distribution and Abundance of Wildlife in Alaska, Key Habitats of Wildlife in Alaska, and Threats to Wildlife.

### Fourth National Climate Assessment: Alaska (Chapter 26)

Much of the data/graphs found in Chapter 26 can conceivably be found on websites included in the Tools Matrix or from other sites found on the U.S. Climate Resilience Toolkit.

### Summary

With regards to the **Online Tools Comparison Matrix** or other online tools, such tools can play a role in the decision making process. First, if no UAS program is in place, such online tools could provide basic background (historical and/or projected) data/information that is often included in planning documents. Such information could complement Traditional Ecological Knowledge. Second, if a UAS program does exist, these online tools could support a UAS program and the decision making process by providing basic (historic and projected) background information, allowing the UAS program to establish a current baseline and undertake ongoing monitoring. Finally, online tools often exclude local data so extrapolating its significance from the regional or state level to the local level may need to be done.

## 4.3. WHAT ARE THE SHORT AND LONG-TERM COST SHARING/ PARTNERSHIP OPPORTUNITIES FOR COMMUNITY MANAGED DATA COLLECTION EFFORTS?

The following table, also included in **Section 2.6 Partnership Options/Considerations Methodology**, outlines the types of relationships that could exist between parties considering development of a UAS program.

| Types of Agreements for Future Unmanned Aircraft Systems Data Collection Services | | |
|---|---|---|
| **Contractee (Retention of Services) or Funding Entity** | **Contractor (Provides Services) or Funding Recipient** | **Type of Agreement (Memorandum of Agreement (MOA), Contract, Cooperative Agreement)** |
| E.g. Native Village of Unalakleet | Consultant providing the service | Can be MOA or contract |
| Community XYZ or Regional Non-Governmental Organization (NGO) | NVU - to collect data | MOAs or contract |
| Agency XYZ | NVU - to collect data | MOAs or contract |
| Partnership | | Partnership Agreement (Formal business structure, generally registered) |
| Multiple Parties | | Cooperative Agreement - Generally based on government-to-government collaboration (Typically an MOA, depending on number of parties and what is being agreed to) |

### 4.3.1. SHORT-TERM COST SHARING/PARTNERSHIP OPPORTUNITIES

**Single-User or Single-Community UAS Program**

Under a Single-User program, an individual community, such as Unalakleet, would first prioritize the nine scientific study areas and their related climate risks. Leaders would then prioritize the top 2-3 study areas to focus on and from which to grow the UAS program due to the startup and operating costs (e.g. drone, sensors, training, pilot certification, insurance, etc.).

**Multiple-User UAS Program**

Building on the Single-User Program, under a Multiple-User Program, a single community, such as Unalakleet, could provide the data collection services to other local/regional communities and/or regional, state or federal entities. The service provider would do so under an agreement such as the **EXAMPLE Professional Services - Memorandum of Agreement** found in **Appendix E**. Critical to such an agreement, is clearly defining (UAS) terminology, data-to-be-collected and analyzed, protocol(s) needed for specified region or location, and obligations and ownership of raw and analyzed data.

The start-up and unit cost analyses for each study area done by Dr. Jessica Garron and Barbara Cozzens is a good place to begin determining an overall program budget and specific study area costs.

### 4.3.2. LONG-TERM COST SHARING/ PARTNERSHIP OPPORTUNITIES

**Single-User or Single-Community UAS Program**

In the long-term, a Single-User UAS Program would build on the short-term UAS program, prioritizing the next set of study areas, baseline data to be collected and monitored needed over time. The community would purchase the related sensors, if not already acquired, accordingly. On-going training and certification renewal may be needed as well as training in scientific standard protocol for the data to be collected.

**Multiple-User UAS Program**

A long-term Multiple-User UAS Program would build on a short-term program, potentially phasing in the data collection for the remaining study areas and monitoring in 2 -3 stages, based on prioritization.

A Multiple-User UAS Program could be structured under one of the following options:

1. One community provides the UAS service; other communities and/or regional, state or federal entities contract for certain aspects of the service.
2. A group of regional communities partner together to establish the program and provide the service to themselves and/or to provide the service to regional, state or federal entities.
3. Purchase all UAS services from an outside entity.

Such a collaborative program could provide economies of scale by sharing costs. Those entities in the program would have to determine and agree to a fee structure. In setting up such a program, developing a business plan would be very helpful, utilizing the cost information provided by Dr. Jessica Garron and Barbara Cozzens.

The multiple-users would also have to identify common baseline needs and monitoring priorities (e.g. coastal erosion, infrastructure monitoring such as bulk fuel and water tanks). They would also have to ensure that scientific standards protocols are adhered to.

An opportunity associated with a Multiple-Use UAS Program is the potential of developing local expertise in the region and expanding workforce training that could be linked to the local area school district Continuing Technical Education (CTE) program.

Finally, the "Contractual Considerations - Example of Professional Services Language" document found in Appendix **E** provides some guidance on developing long-term relationships. It is a template, per the State of Alaska's governing laws, and for Example Purposes ONLY. Before finalizing any such document, legal advice should be sought to ensure all sections are legally applicable.

## 4.4. WHAT ARE THE RESILIENCE-RELATED INFORMATION NEEDS OF POTENTIAL USERS (E.G. FEDERAL AND STATE AGENCIES, NORTON SOUND VILLAGES, AND REGIONAL ENTITIES) OF LIDAR AND/OR OTHER AERIAL SYSTEM-COLLECTED DATA?

In order for data to be accepted by other users, whether federal and state agencies, Norton Sound Villages and/or regional entities, protocols for data collection under the scientific study areas and emergency responses must be defined and agreed to by those collecting the data and those needing the data. Further, all flight protocols will follow the guidelines set forth in 14 CFR Part 107 - Small Unmanned Aircraft Systems. All flights will be conducted by pilots flying under Part 107 certification defined in Subpart C (Remote Pilot Certification) as civil operators, or under a Certificate of Authorization as a governmental operator under the statutory requirements of 49 Code 40102(a) and 40125 for public aircraft.

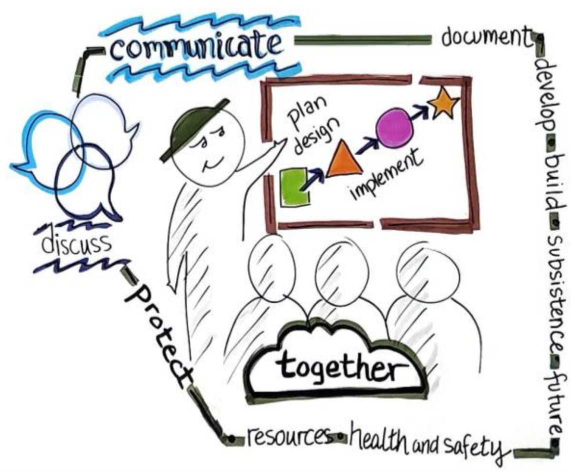
Following established protocols in terms of resilience-related information needs, areas of critical importance include infrastructure monitoring, especially related to bulk fuel tanks, and the ability to assess fuel spills that may happen because of tank leakage or spillage from increased shipping traffic. In the event of responding to a crisis, UAS observation can collect and provide critical real-time data/information to both those on-the-ground but also federal and/or state agencies that may be responding and/or providing additional resources.

As discussed in the **Section 4.2.2. UAS and Online Tools Data Integration into Local, State, And Federal Plans and Reports**, UAS-collected data can have a role in a community's drafting and/or updating of its Hazard Mitigation Plan (HMP). Working together with the Federal Emergency Management Agency (FEMA) or consultant helping to draft the HMP, such data can increase understanding of coastal erosion with base flood elevation data; improve flood preparations with digital elevation models; enhance risk analysis for infrastructure using maps of high risk facilities; take air and water quality samples for public health risk assessment; and provide cultural and historical site risk analysis.

Finally, a concern by various Norton Sound Villages is the potential of increased mining exploration and mining (extractable resources) in the region, if permitted, and their impact to fishing and hunting areas, as well as water quality. As a pre-emptive measure, being able to establish a baseline for the areas where leases might be sold, could be critical along with ongoing monitoring.

## 4.5. HOW CAN WE EFFECTIVELY SHARE FINDINGS WITH TRIBAL COUNCIL MEMBERS AND OTHER INTERESTED, APPROPRIATE PARTIES TO DETERMINE NEXT STEPS AND LONG-TERM PROJECT FEASIBILITY?

The Project Team shared initial project findings with interested and appropriate parties starting in 2020. In February 2020, the Team made a presentation at the Alaska Forum on the Environment (AFE) entitled, *Coastal Alaska Communities Feasibility & Sustainability of Real-Time Data Collection with UAS for Climate-Related Problems & Decision-Making in Rural Alaska*. A project survey was sent out in April 2020 to Alaska Tribal Council Chairs and Coordinators, City Council Managers, and regional IGAP Coordinators. Background information on the project was provided in the cover letter. Finally, in October 2020, a final project webinar entitled, *Improving Local Decision Making in Alaskan Communities with Drones and Online Climate Data Tools*, was held. Invitations to this event were not only sent to the April Survey list, other identified interested parties, but  shared through the Alaska Native Tribal Health Consortium's Center for Environmentally Threatened Communities September e-newsletter, (https://anthc.org/center-for-environmentally-threatened-communities/). In the original project work plan, a regional face-to-face meeting was planned but, because of COVID 19, did not happen.



In terms of next steps, the Native Village of Unalakleet Project Manager will present the Native Village of Unalakleet Tribal Council with a copy of the final Feasibility Study for their review and acceptance of the document. Pending Council approval, greater circulation of the Study and its findings will take place. Cutting edge information is contained in the report. Both Dr. Jessica Garron's research on UAS set up and training costs related to the 9 scientific study areas, as well as Barbara Cozzen's Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis, have not been done before to the extent they are here. The intent is to share this information not only with other communities but also with a broader technical audience.

The **Online Tools Comparison Matrix** has also presented a unique way of analyzing web based tools. As stated earlier, the overall project and spreadsheet were presented to the Alaska Native Tribal Health Consortium (ANTHC) as a potential home for the resource. Collectively, the Native Village of Unalakleet (NVU), the Model Forest Policy Program (MFPP) and ANTHC decided a future project together was worth exploring. Unfortunately, the timing is not good for ANTHC, hence another home needs to be sought for the climate tools list that could benefit community climate adaptation planning across Alaska. Possible entities that could be approached are the University of Alaska Fairbanks - Alaska Center for Climate Assessment and Policy (ACCAP) or Scenarios Network for Alaska + Arctic Planning (SNAP), both part of the International Arctic Research Center; the U.S. Climate Resilience Toolkit; and/or possibly shared on a Norton Sound regional basis with Kawerak. If successful, concrete steps towards long-term sustainability of this Project component will take place.

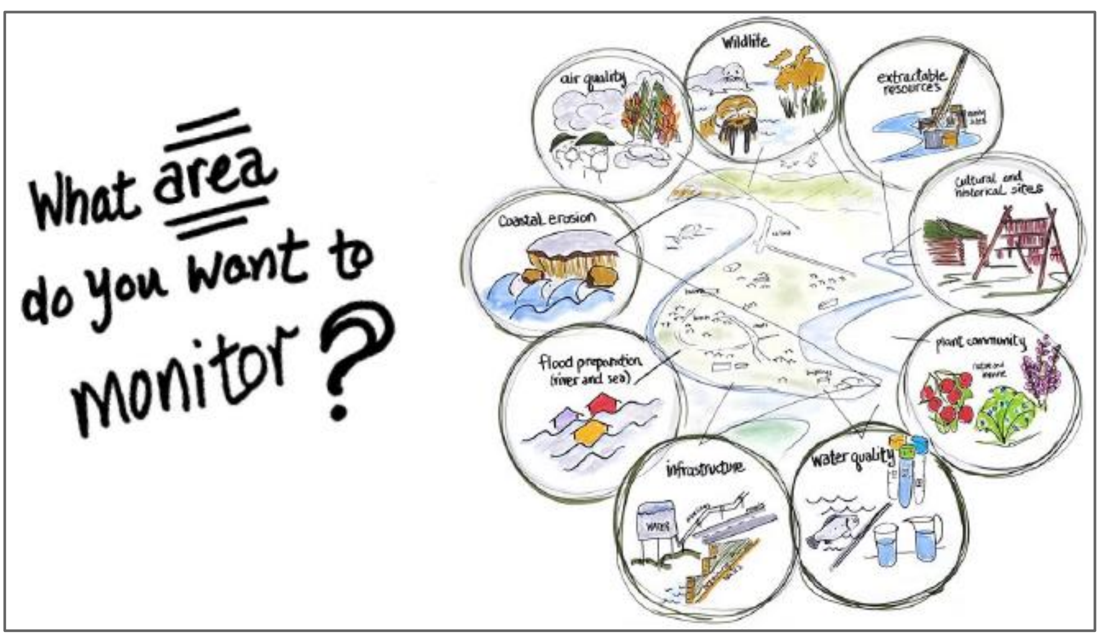
The Center for Environmentally Threatened Communities will write an article on the final Feasibility Study when approved for release.

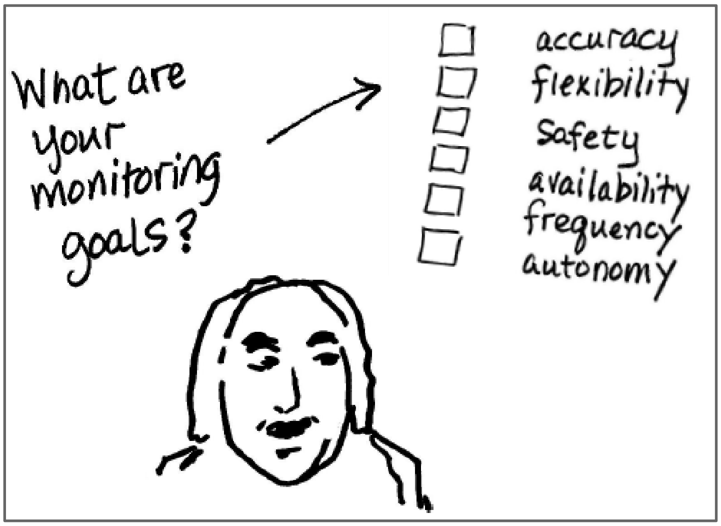
Finally, the project is evolving into its next phase, taking steps towards long-term sustainability of a UAS program in Unalakleet and the Bering Strait region. The University of Alaska Fairbanks - Alaska Center for Unmanned Aircraft Systems Integration (ACUASI) submitted a proposal, *Remote Unmanned Aircraft System (UAS) Inspection and Response Team Development in the Bering Strait Region*, that received funding in Fall 2020 from the Arctic Domain Awareness Center (ADAC), A Department of Homeland Security Center of Excellence, housed at the University of Alaska Anchorage. The goal of this project is to integrate remote sensing tools, such as unmanned aircraft systems (UAS), into the operational environment of remote, sparsely populated, western Alaska to increase the efficiency of USCG infrastructure inspection missions, while supporting the expansion of community Science, Technology, Engineering and Math (STEM) capacity. To demonstrate this concept, the program will train a set of UAS pilots, (equipped with U.S. manufactured UAS platforms) in the Bering Strait hub community of Unalakleet, Alaska, to conduct infrastructure inspections, specifically oil-containing infrastructure, and emergency response (ER) actions in support of local and/or regional crisis. This project will run through April 2022. Project updates will take place from the local level to the national level, as approved by the Native Village of Unalakleet. ADAC will also house a project website.

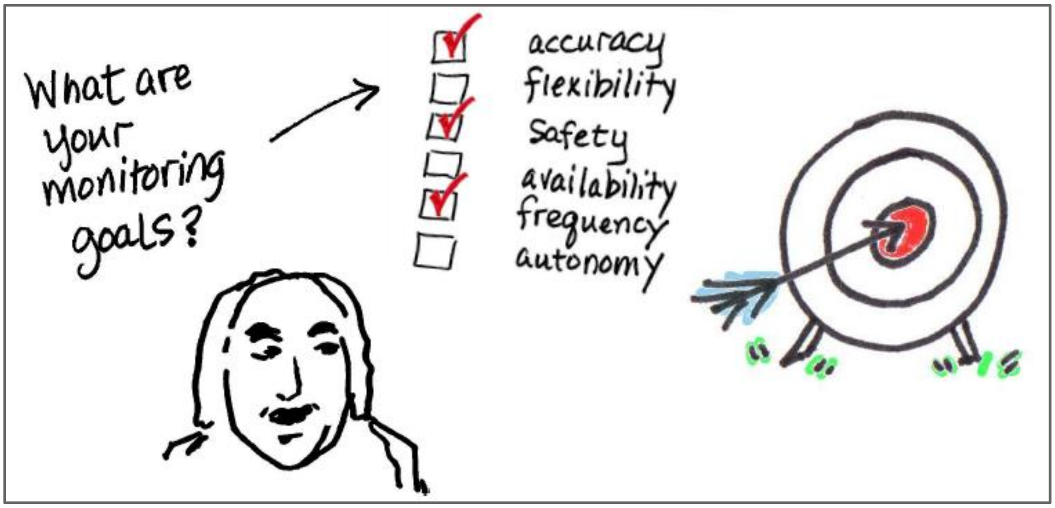
# 5. NEXT STEPS / RECOMMENDATIONS

## 5.1. IS A UAS PROGRAM FOR CLIMATE DECISION MAKING THE BEST WAY TO GO FOR RURAL ALASKA VILLAGES/COMMUNITIES?

A community-based UAS program can provide local control and local self-determination. It can build local capacity through increased vocational training and economic opportunities for the community. Challenges though include the set up and ongoing costs (e.g. training, maintenance, etc.) and ensuring that strict scientific standard protocols are followed. To help decide whether a community should invest in developing a UAS program, the following visual synthetization was created by Anne Jess of The Doodle Biz (www.TheDoodleBiz.com). - It may seem overly simple but the graphics capture the essence of the questions that need to be asked.


What are your monitoring goals?
accuracy
flexibility
Safety
availability
frequency
autonomy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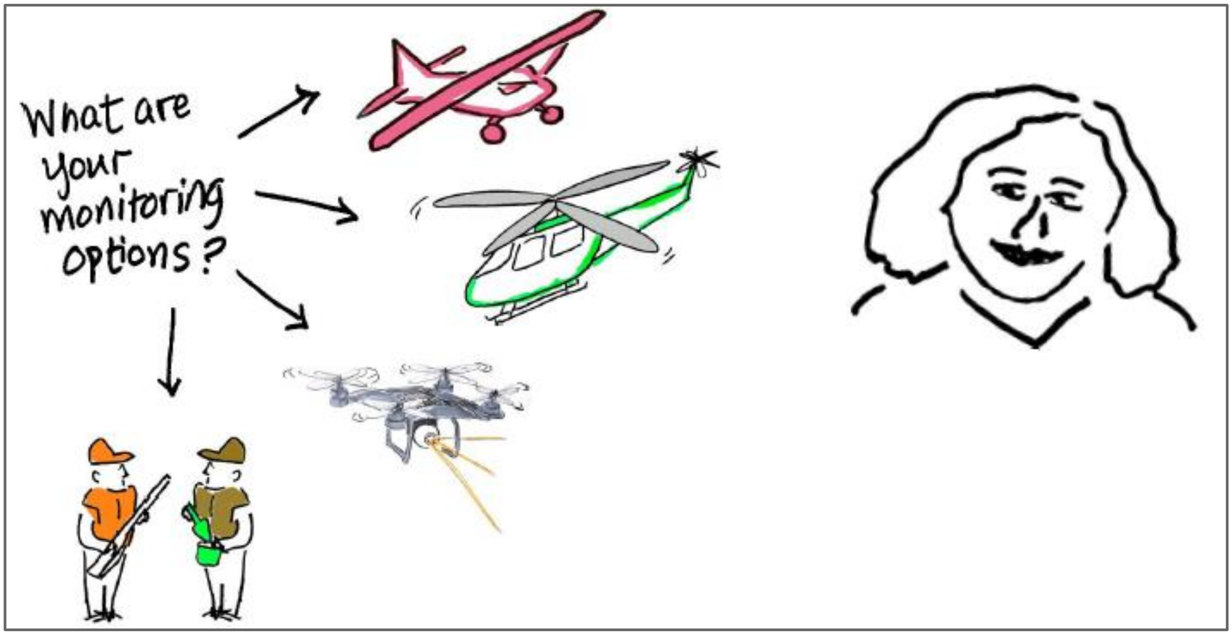
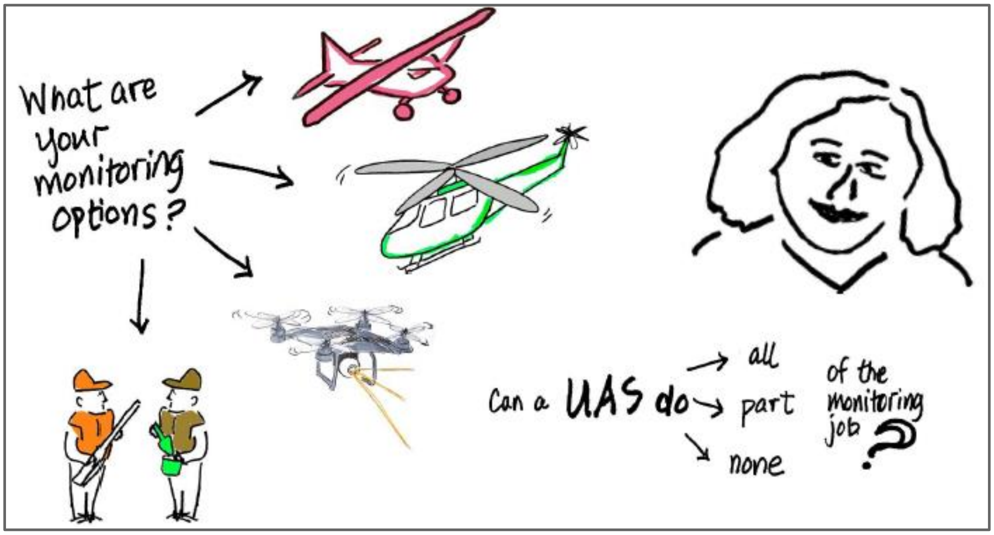
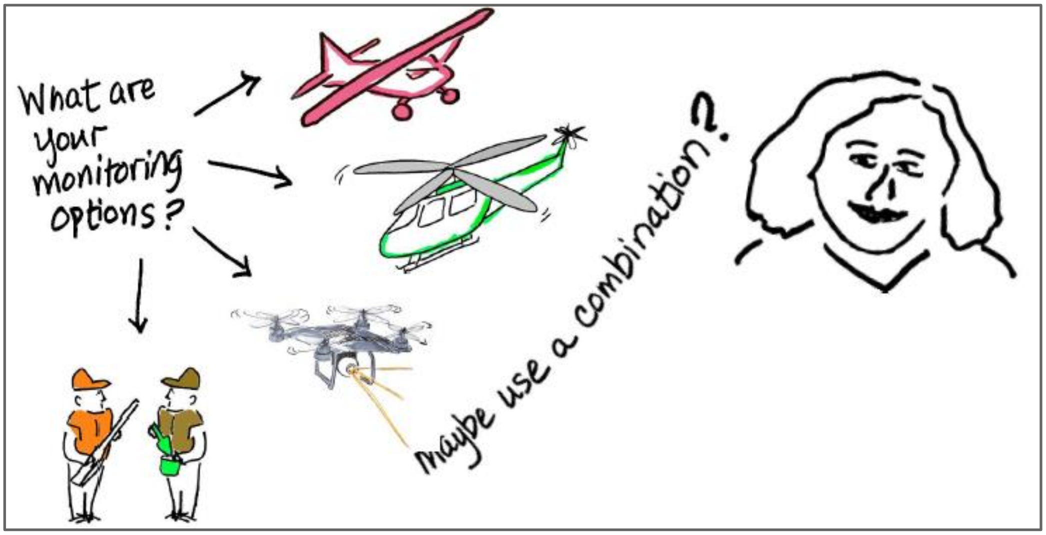
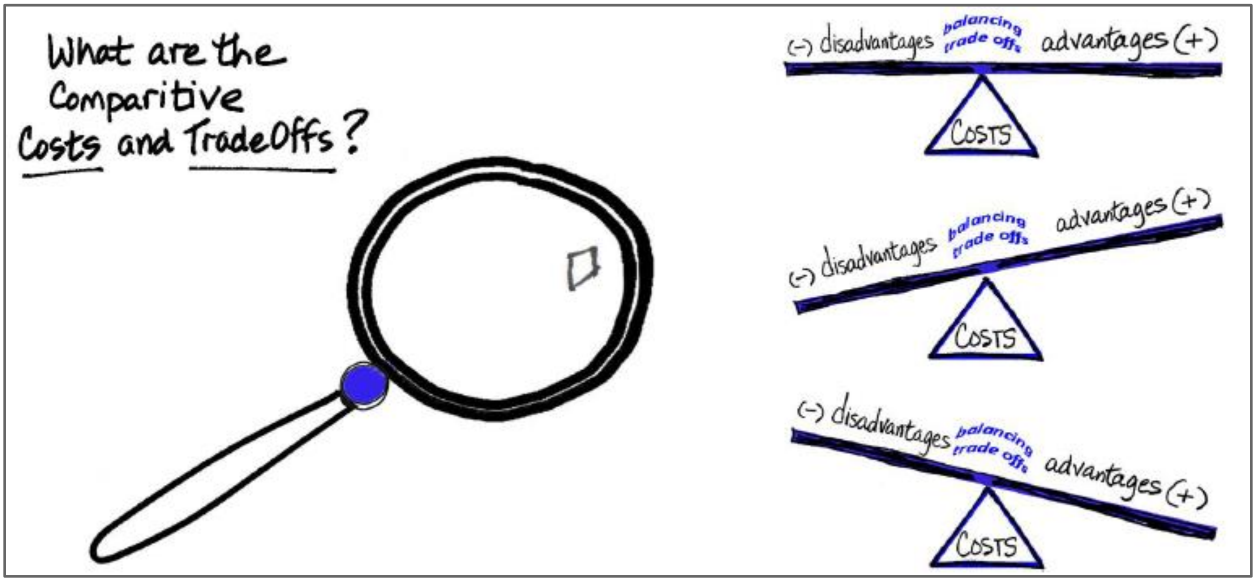
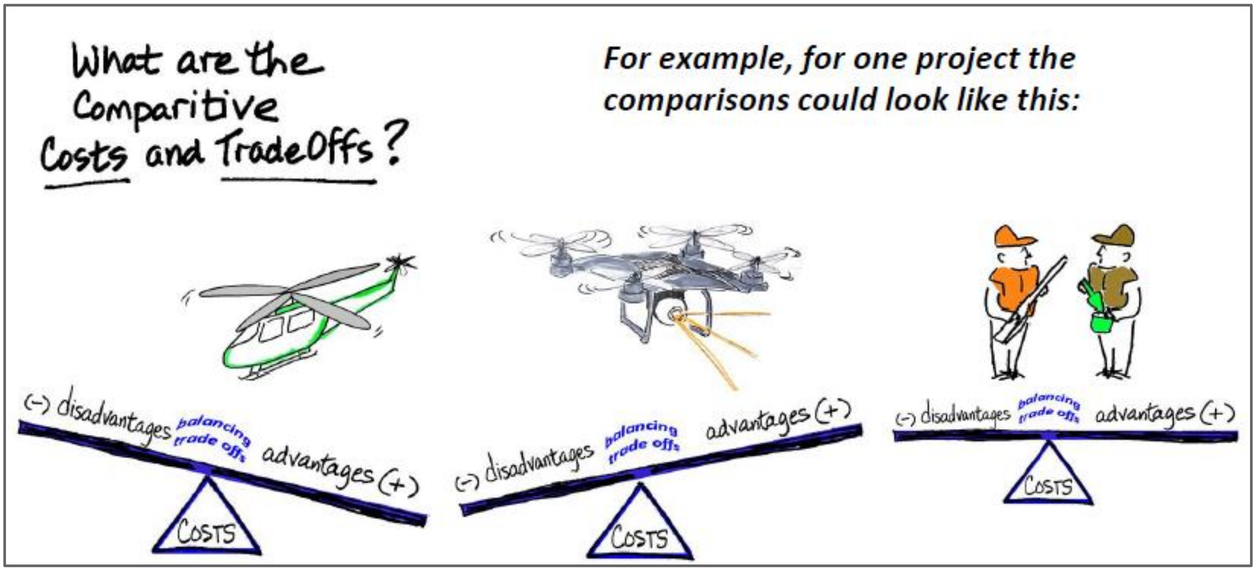
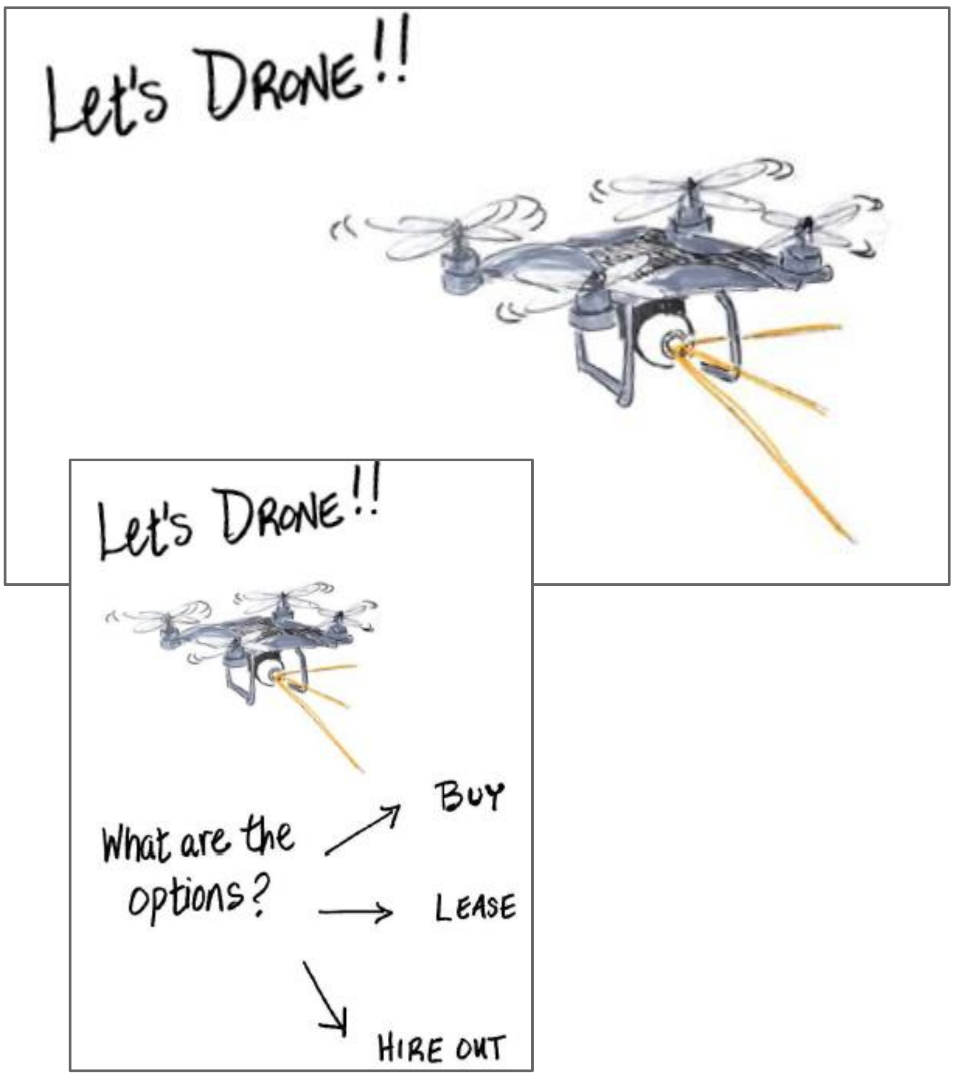

What are your monitoring options?

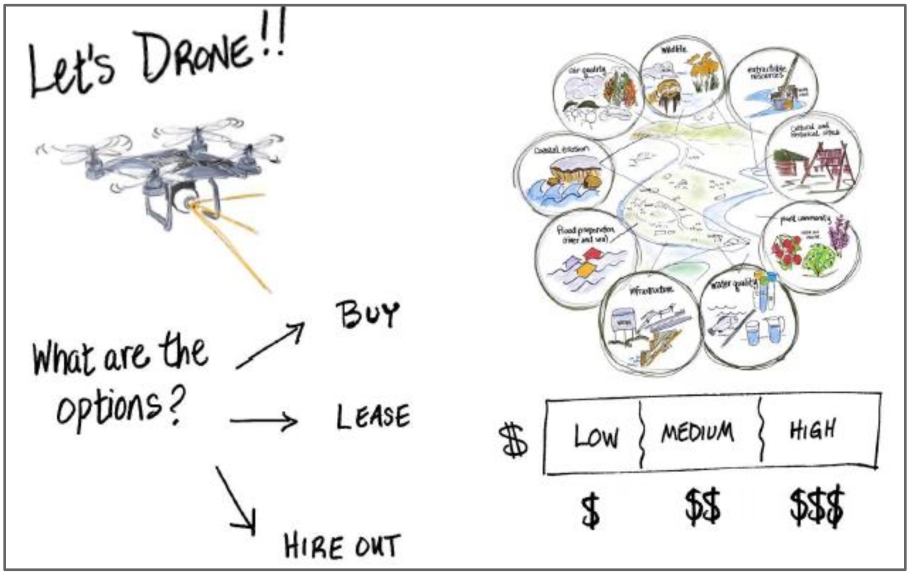

What are your monitoring options?
Can a UAS do → all / part / none
of the monitoring job?

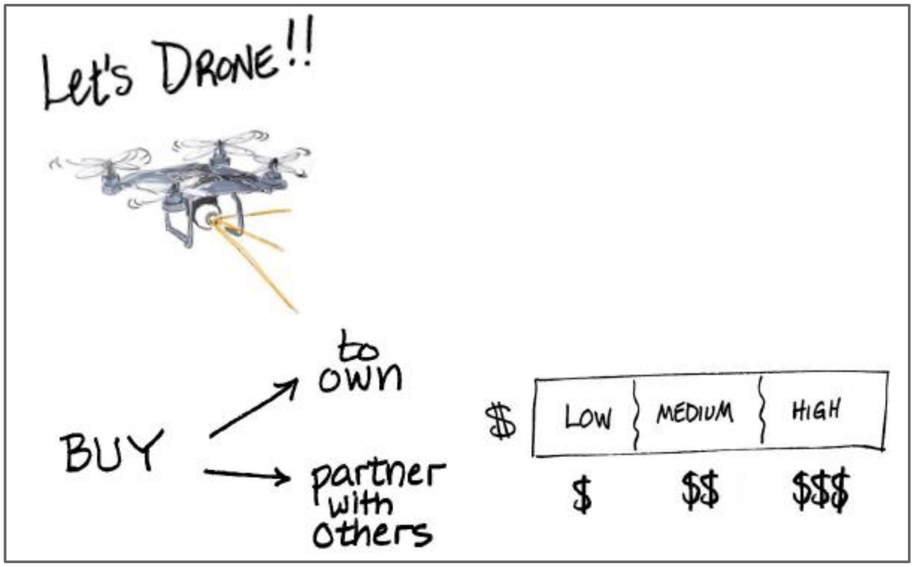

What are your monitoring options?
maybe use a combination?

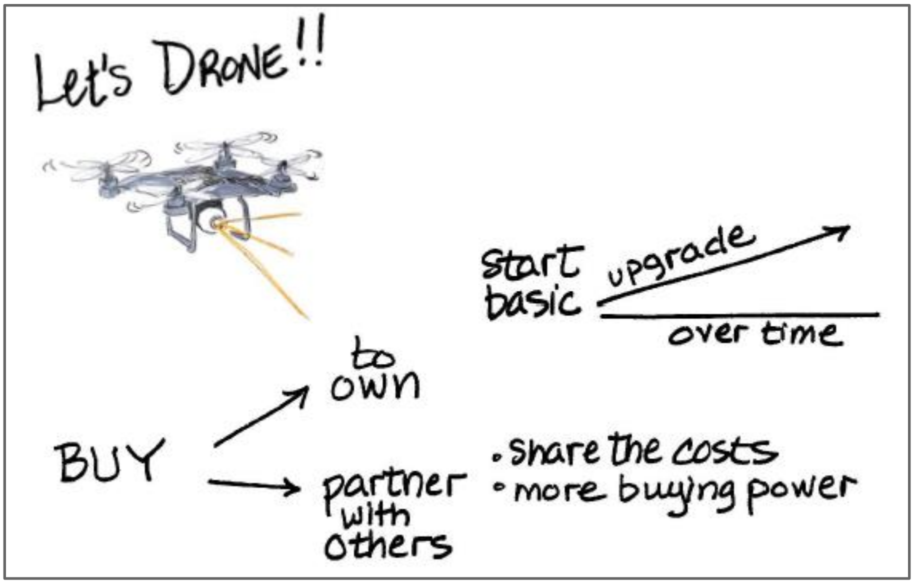

What are the Comparitive Costs and TradeOffs?
(–) disadvantages balancing trade offs advantages (+)
COSTS
(–) disadvantages balancing trade offs advantages (+)
COSTS
(–) disadvantages balancing trade offs advantages (+)
COSTS

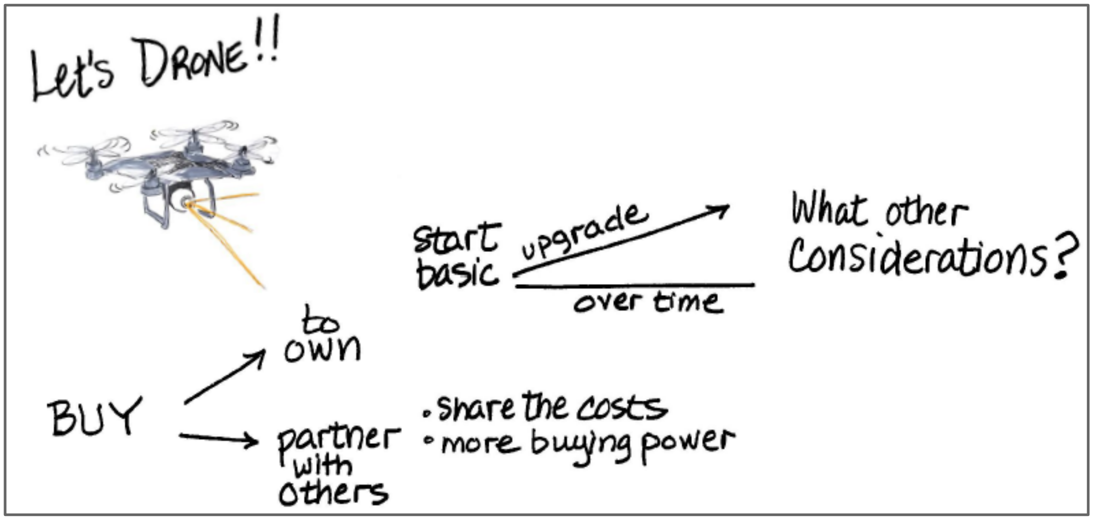

What are the Comparitive Costs and TradeOffs?
For example, for one project the comparisons could look like this:
(–) disadvantages
balancing trade offs
advantages (+)
COSTS
(–) disadvantages
balancing trade offs
advantages (+)
COSTS
(–) disadvantages
balancing trade offs
advantages (+)
COSTS

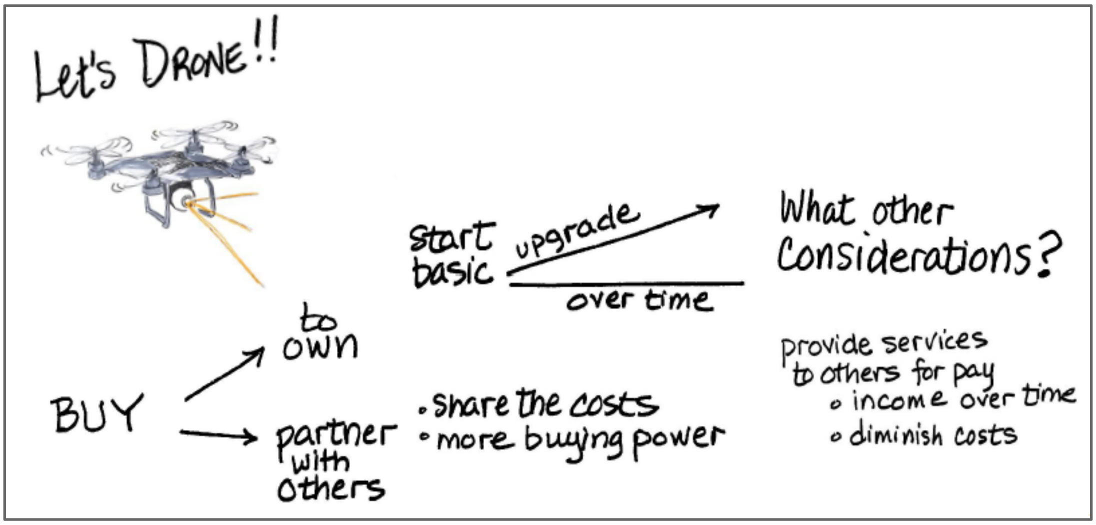

Let's DRONE!!
Let's DRONE!!
What are the options?
BUY
LEASE
HIRE OUT


Let's DRONE!!
What are the options?
BUY
LEASE
HIRE OUT
\$
LOW
MEDIUM
HIGH
\$
\$\$
\$\$\$


Let's DRONE!!
BUY
to own
partner with others
\$
LOW
MEDIUM
HIGH
\$
\$\$
\$\$\$


Let's DRONE!!
start basic
upgrade
over time
BUY
to own
partner with others
• share the costs
• more buying power




**Section 5.2. Recommendations** below will go over in greater detail the visual concepts presented above as well as address additional questions and recommendations for consideration.

## 5.2. RECOMMENDATIONS

As stated in the **Introduction**, the ***<u>Project Goal</u>* was to build local and regional capacity to address future ocean and coastal management planning and long-term resilience through the establishment of a self-sustaining, rigorous, localized and on-going data collection and analysis program.** To that end, the Project Team analyzed the feasibility of establishing a regional data collection program utilizing an unmanned aircraft system (UAS) (drone and sensors) compared to other data collection systems. The Chapters above outlined the research questions guiding the study and methodology, provided an in-depth literature review, presented research results, and discussed the research questions before addressing next steps and recommendations.

**<u>DETERMINING IF A UAS PROGRAM IS RIGHT FOR YOUR COMMUNITY</u>**

Answers to the questions below and those presented in the sections above will help drive whether your community decides to invest in such a UAS program…fully, partially, in phases, or not at all.

- ➢ Is cost or data the driving factor for implementing a UAS-based program or is it a balance between the two?
- ➢ Does the current Traditional Ecological Knowledge (TEK) and available scientific data meet your community long-term needs or is there a need to have more locally collected data in order to make sound comprehensive, long-term (planning) decisions?
- ➢ Does your community want to monitor certain scientific study areas on an ongoing basis or does it just want a snapshot in time?
- ➢ Is your community willing to invest in the necessary on-going training and related operational expenses?
- ➢ Does your community want to build local job skills and/or a vocational training program?
- ➢ Finally, does your community want to have greater control of local data collection?

**<u>UAS AND COST ESTIMATING / ANALYSIS</u>**

In short, of the nine scientific study areas, UAS is only logical for examining some of their components, not all of them at this time. The most critical and easily achievable baseline data collection and ongoing monitoring with sUAS in rural Alaska can be accomplished with EO, infrared and multispectral sensors. With minimal post-processing, these sensors can be used to monitor various aspects of all nine scientific study areas highlighted in this study, but are the least valuable for monitoring air quality. In addition, UAS can be an incredible asset during a Search and Rescue mission and/or assessment of a local emergency event. Hence, phasing in a UAS program makes the most sense based on a community's priorities.

**<u>UAS-based monitoring solutions for rural Alaska</u>** - A deep dive was done by Dr. Garron during the literature review on different remote sensing solutions and UAS options for monitoring remote Alaska, highlighting the need for an operational, on-the-ground solution for a small (remote) community, focused on what is reasonably attainable and sustainable over time. The solutions that make the most sense are electro optical (EO) and infrared (IR) sensors integrated in a commercial off the shelf (COTS) drone. EO and IR sensors are the most mature sensors. These tools have the most processing products to support them and are the most intuitive. Automating as many routines as possible through quality metadata capture and application will be key for the creation of repeatable UAS-based data collection flights over monitoring targets.

As discussed in the Results chapter, there are a number of ways to use the UAS-derived data products, the most functional being the video capture and mapping capacity of the UAS and its associated sensors. Pairing UAS derived information with other data allows for deeper scientific analysis if that is a goal. For example, using UAS-collected imagery in combination with physical coastline parameters like slope, sediments, tides, winds, elevation, may allow for the prediction of lower or higher erosion along the Bering Sea coastline (adapted from Marrero et al., 2019). But if such data collection is not supporting the community need, the effort should be kept as minimal as required to answer key scientific questions.

**Cost estimating and analysis of operational UAS**, Barbara Cozzens' study, Environmental Monitoring with Unmanned Aerial Vehicles: Cost Estimating & Analysis, found in Appendix D, provides a good starting place for understanding the fragmented data on UAV data collection and cost analysis in the context of the nine study areas. Given the scarcity of historical cost data and analyses, the number of study areas, and the variety of environmental contexts, scales, constraints, and variables that could be assessed with UAV systems, estimates within the study should be used with care. However, these estimates can serve as guideposts to help inform and strengthen decisions.

UAV monitoring and/or sampling indicated greater advantages than traditional methods for certain applications related to certain study areas (e.g. coastal erosion, flooding, infrastructure, water quality, vegetation between 10 and 20 hectares (ha)). Even for areas without a clear cost advantage though, UAVs proved to improve efficiency of monitoring or sampling, provide access to remote or inaccessible areas, and reduce risks to human health and safety, hence worth assessing whether the investment in UAV program meets a community's needs. Again such a program could be phased in and/or undertaken with another community or group of communities to help share the start-up and longer-term operational costs.

## ONLINE CLIMATE TOOLS MATRIX

Alaskan communities have available an array of free environmental and climate tools developed by government agencies, science groups, universities, and other tribal organizations. Unfortunately, these tools are often a challenge to find, time consuming, complicated, data heavy, and it is not always clear whether a given tool is (a) relevant to the particular challenges faced by a community, (b) applicable to the specific geography of the community, and (c) usable by a community given other constraints. Tools can provide baseline information that could assist with long-term decision making. The Online Tools Comparison Matrix (Matrix) works to identify and organize a sample of tools most applicable to the different scientific study areas, or used to supply complimentary data sets to those collected by UAVs. Though the Matrix emphasis is Unalakleet, it can be used by other Alaska communities.

## UAS AND ONLINE TOOLS DATA INTEGRATION/ADAPTATION INTO LOCAL, STATE, AND FEDERAL PLANS AND REPORTS

The integration and application of UAS data into planning and decision making processes can be a valuable upgrade in quality and effectiveness at local, state, and federal levels. There are benefits to the quality and completeness of visual and scientific data available, improved collaborative process outcomes, and overall more effective risk assessment and adaptive strategy development.

With regards to the Online Tools Comparison Matrix or other online tools, such tools can play a role in the decision making process, either as a standalone resource or complementing a UAS program. Online tools often exclude local data so extrapolating its significance from the regional or state level to the local level may need to be done.

## RESEARCH LIMITATIONS AND FUTURE WORK

Adequate funding was a key limitation to researching all nine scientific study areas (start-up) operational solutions. An in-depth literature review was done by Dr. Garron for all study areas but a deep dive into identifying the technology and training needs and costs for high, medium, and low options was only completed for the monitoring of four study areas (coastal erosion, flood preparation (river and sea), infrastructure, and water quality) considered at highest risk related to climate change. Future work is needed to confirm the operational solutions for the other five scientific study areas (air quality, cultural and historical site identification and monitoring, wildlife surveys, plant community monitoring, extractable resource identification and monitoring) and to identify the start-up costs in comparison to ground-based or contracted aerial surveys over Unalakleet and nearby landscape.

In terms of limitations on operational cost comparison analysis, as noted by Barbara Cozzens in her study, there are dissimilarities between the study site and the policy site, the method used to transfer values, lack of consistency in reporting scales, errors in rescaling, and researcher reporting or calculating. Drone technology is changing rapidly though, which should improve production efficiencies and costs. When used in the field, these new capabilities may change the cost or accuracy comparisons dramatically. As the use of UASs increases for collection of localized baseline data and on-going monitoring, there will be an increase in cost data, the number of study areas, and the variety of environmental contexts, scales, constraints, and variables. In turn, this increase will provide updated cost estimates that have greater confidence.

## SIGNIFICANCE OF WORK

The research and findings contained in this document have significance and applicability beyond Unalakleet on several different levels. First, the in-depth literature review and/or a comparison of cost estimates related to the nine scientific study areas, which was done by Dr. Garron and Barbara Cozzens, has not been done to the extent that it has been for this study, establishing critical baselines in current UAS applications. Second, the aggregation of the online tools matrix and the potential of transitioning it into an online system that can be used by other Alaska communities in a meaningful way have not been done before. Third, the analysis of using both UAS collected data and online data to complement Traditional Ecological Knowledge (TEK) will help in the decision making process, especially related to setting baselines and ongoing monitoring. All are critical in dealing with short, mid and long-term climate risks from different perspectives. --- Sharing this Feasibility Study and its findings with a broader audience is recommended.

# 6. BIBLIOGRAPHY

Aasen, H., Burkart, A., Bolten, A., & Bareth, G. (2015). Generating 3D hyperspectral information with lightweight UAV snapshot cameras for vegetation monitoring: From camera calibration to quality assurance. *ISPRS Journal of Photogrammetry and Remote Sensing*, *108*, 245–259. https://doi.org/10.1016/j.isprsjprs.2015.08.002

Adamopoulos, E., & Rinaudo, F. (2020). UAS-Based Archaeological Remote Sensing: Review, Meta-Analysis and State-of-the-Art. *Drones*, *4*(3). https://doi.org/https://doi.org/10.3390/drones4030046

Adão, T., Hruška, J., Pádua, L., Bessa, J., Peres, E., Morais, R., & Sousa, J. J. (2017). Hyperspectral imaging: A review on UAV-based sensors, data processing and applications for agriculture and forestry. *Remote Sensing*, *9*(11). https://doi.org/10.3390/rs9111110

Agudo, P.; Pajas, J.; Pérez-Cabello, F.; Redón, J.; Lebrón, B. (2018). The Potential of Drones and Sensors to Enhance Imagery., Detection of Archaeological Cropmarks: A Comparative Study between Multi-Spectral and Thermal. *Drones*, *2*(29).

Alam, M. S., & Sidike, P. (2012). Trends in Oil Spill Detection via Hyperspectral Imaging. *Electrical & Computer Engineering (ICECE), 2012 7th International Conference*, 858–862.

Alaska Department of Fish and Game. (2015). Alaska Wildlife Action Plan. 228 p.

Alaska Department of Natural Resources, Office of History and Archology. (2021). Alaska Heritage Resources Survey. Retrieved from http://dnr.alaska.gov/parks/oha/ahrs/ahrs.htm

Alaska Division of Homeland Security & Emergency Management. (2021). Small Community Emergency Response Plan. Retrieved from https://ready.alaska.gov/Plans/SCERP

Alaska Division of Homeland Security & Emergency Management. (2017). Alaska Emergency Response Guide for Small Communities. 84 p.

Alfredsen, K., Haas, C., Tuhtan, J. A., & Zinke, P. (2018). Brief Communication: Mapping river ice using drones and structure from motion. *Cryosphere*, *12*(2), 627–633. https://doi.org/10.5194/tc-12-627-2018

Alvarado, M., Gonzalez, F., Fletcher, A., & Doshi, A. (2015). Towards the development of a low cost airborne sensing Sensors, system to monitor dust particles after blasting at open-pit mine sites. *Sensors*, *15*, 19667–19687.

Andreoli, G., Bulgarelli, B., Hosgood, B., & Tarchi, D. (2007). *Hyperspectral Analysis of Oil and Oil-Impacted Soils for Remote Sensing Purposes*.

Angliss, R. P., Ferguson, M. C., Hall, P., Helker, V., Kennedy, A., & Sformo, T. (2018). Comparing manned to unmanned aerial surveys for cetacean monitoring in the Arctic: methods and operational results. *Journal of Unmanned Vehicle Systems*, *6*(3), 109–127. https://doi.org/10.1139/juvs-2018-0001

Armanini, S. F., Polak, M., & Gautrey, J. E. (2016). Decision-making for unmanned aerial vehicle operation in icing conditions. *CEAS Aeronaut J*, *7*, 663–675. https://doi.org/https://doi.org/10.1007/s13272-016-0215-2

Arnborg, L., Walker, H. J., & Peippo, J. (1966). Water discharge in the Colville River. *Phys. Geogr.*, *48*, 195–210.

Beamish, A., Raynolds, M. K., Epstein, H., Frost, G. V., Macander, M. J., Bergstedt, H., … Wagner, J. (2020). Recent trends and remaining challenges for optical remote sensing of Arctic tundra vegetation: A review and outlook. *Remote Sensing of Environment*, *246*(March), 111872. https://doi.org/10.1016/j.rse.2020.111872

Beretta, F., Rodrigues, A. L., Peroni, R. L., & Costa, J. F. C. L. (2019). Automated lithological classification using UAV and machine learning on an open cast mine. *Appl. Earth Sci.*, *128*, 79–88.

Berni, J. A. J., Zarco-Tejada, P. J., Suárez, L., González-Dugo, V., & Fereres, E. (2008). Remote sensing of vegetation from UAV platforms using lightweight multispectral and thermal imaging sensors. *Int. Arch. Photogramm. Remote Sens. Spatial Inform. Sci*, *38*, 6 pp.

Besada, J. A., Bergesio, L., Campaña, I., Vaquero-Melchor, D., López-Araquistain, J., Bernardos, A. M., & Casar, J. R. (2018). Drone mission definition and implementation for automated infrastructure inspection using airborne sensors. *Sensors (Switzerland)*, *18*(4), 1–29. https://doi.org/10.3390/s18041170

Bieniek, P. A., Bhatt, U. S., Rundquist, L. A., Lindsey, S. D., Zhang, X., & Thoman, R. L. (2011). Large-Scale Climate Controls of Interior Alaska River Ice Breakup. *J. Climate*, *24*, 286–297. https://doi.org/doi:10.1175/2010JCLI3809.1

Blix, K., Pálffy, K., Tóth, V. R., & Eltoft, T. (2018). Remote sensing of water quality parameters over Lake Balaton by using Sentinel-3 OLCI. *Water*, *10*(10), 1–20. https://doi.org/10.3390/w10101428

Bouvier, M., Durrieu, S., Gosselin, F., & Herpigny, B. (2017). Use of airborne lidar data to improve plant species richness and diversity monitoring in lowland and mountain forests. *PLoS ONE*, *9*(2), e0184524.

Calleja, J. F., Pagés, O. R., Díaz-Álvarez, N., Peón, J., Gutiérrez, N., Martín-Hernández, E., … Álvarez, P. F. (2018). Detection of buried archaeological remains with the combined use of satellite multispectral data and UAV data. *Int. J. Appl. Earth Obs. Geoinf.*, *73*, 555–573.

Chirico, P. G., & DeWitt, J. D. (2017). Mapping informal small-scale mining features in a data-sparse tropical environment with a smal UAS. *J. Unmanned Veh. Syst.*, *5*, 69–91.

Christiansen, F., Rojano-Doñate, L., Madsen, P. T., & Bejder, L. (2016). Noise levels of multi-rotor unmanned aerial vehicles with implications for potential underwater impacts on marine mammals. *Frontiers in Marine Science*, *3*(DEC), 1–9. https://doi.org/10.3389/fmars.2016.00277

City of Unalakleet HMP Planning Team, Hazard Mitigation Planning Team (2015). City of Unalakleet Hazard Mitigation Plan. No online link available.

Clement, J. P., Bentson, J. L., & Kelly, B. P. (2013). *Managing for the Future in a Rapidly Changing Arctic*. 59. Retrieved from http://www.arctic.gov/publications/related/ArcticReport-03April2013PMsm.pdf

Code of Federal Regulations. *Small unmanned aircraft systems*. , (2016).

Colomina, I., & Molina, P. (2014). Unmanned aerial systems for photogrammetry and remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, *92*, 79–97. https://doi.org/10.1016/j.isprsjprs.2014.02.013

Dawei, Z., Lizhuang, Q., Demin, Z., Baohui, Z., & Lianglin, G. (2020). Unmanned Aerial Vehicle (UAV) Photogrammetry Technology for Dynamic Mining Subsidence Monitoring and Parameter Inversion: A Case Study in China. *IEEE Access*, *8*, 16372–16386.

Dering, G. M., Micklethwaite, S., Thiele, S. T., Vollgger, S. A., & Cruden, A. R. (2019). Review of drones, Photogrammetry and emerging sensor technology for the study of dykes: Best practises and future potential. *J. Volcanol. Geotherm. Res.*, *373*, 148–166.

Devereux, B. J., Amable, G. S., & Crow, P. (2008). Visualisation of LiDAR terrain models for archaeological feature detection. *Antiquity*, *82*, 470–479.

Dinh, T. D., Primagomedov, R., Pham, V. D., Ahmed, A. A., Kirichek, R., Glushakov, R., & Vladyko, A. (2019). Unmanned aerial system–assisted wilderness search and rescue mission. *International Journal of Distributed Sensor Networks*. https://doi.org/https://doi.org/10.1177/1550147719850719

Doukari, M., Batsaris, M., Papakonstantinou, A., & Topouzelis, K. (2019). A protocol for aerial survey in coastal areas using UAS. *Remote Sensing*, *11*(16). https://doi.org/10.3390/rs11161913

Du, J., Watts, J. D., Jiang, L., Lu, H., Cheng, X., Duguay, C., … Tarolli, P. (2019). Remote sensing of environmental changes in cold regions: Methods, achievements and challenges. *Remote Sensing*, *11*(16), 1–36. https://doi.org/10.3390/rs11161952

Dufek, J., Traore, S., Swanson, C., Fipps, G., & Murphy, R. (2019). Preventing Irrigation Canal Breaches Using Small Unmanned Aerial System with Multispectral Payload. *2019 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*, 133–138.

Eicken, H., Mahoney, A., Jones, J., Heinrichs, T., Broderson, D., Statscewich, H., … Zhang, J. (2016). Sustained observations of changing Arctic coastal and marine environments and their potential contribution to Arctic maritime domain awareness: A case study in northern Alaska H. *Arctic*, 1–53.

El-magd, I. A., Kafrawy, S. El, & Farag, I. (2014). *Detecting Oil Spill Contamination Using Airborne Hyperspectral Data in the River*. (April), 140–150.

Emran, B., Tannant, D., & Najjaran, H. (2017). Low-Altitude Aerial Methane Concentration Mapping. *Remote Sensing*, *9*(823). https://doi.org/10.3390/rs9080823

Fang, Y., Hu, Z., Xu, L., Wong, A., & Clausi, D. A. (2019). Estimation of Iron Concentration in Soil of a Mining Area from UAV-Based Hyperspectral Imagery. *Proceedings of the 2019 10thWorkshop on*

*Hyperspectral and Signal Processing: Evolution in Remote Sensing (WHISPERS)*, 1–5. Amsterdam, the Netherlands.

Feng, Q., Liu, J., & Gong, J. (2015). Urban Flood Mapping Based on Unmanned Aerial Vehicle Remote Sensing and Random Forest Classifier—A Case of Yuyao, China. *Water*, *7*(4), 1437–1455.

Fenger-Nielsen, R., Hollesen, J., Matthiesen, H., Andersen, E. A. S., Westergaard-Nielsen, A., Harmsen, H., & Michelsen, A.; Elberling, B. (2019). Footprints from the past: The influence of past human activities on vegetation Greenland, and soil across five archaeological sites in Greenland. *Sci. Total Environ.*, *654*, 895–905.

Fonstad, M. A., Dietrich, J. T., Courville, B. C., Jensen, J. L., & Carbonneau, P. E. (2013). Topographic structure from motion: a new development in photogrammetric measurement. *Earth Surface Processes and Landforms*, *38*(4), 421–430.

Gao, J., Hu, Z., Bian, K., Mao, X., & Song, L. (2020). AQ360: UAV-aided Air Quality Monitoring by 360-Degree Aerial Panoramic Images in Urban Areas. *IEEE Internet of Things Journal*, *4662*, 1–1. https://doi.org/10.1109/jiot.2020.3004582

Gao, R. S., Telg, H., McLaughlin, R. J., Ciciora, S. J., Watts, L. A., Richardson, M. S., … Fahey, D. W. (2016). A light-weight, high-sensitivity particle spectrometer for PM2.5 aerosol measurements. *Aerosol Science and Technology*, *50*(1), 88–99. https://doi.org/10.1080/02786826.2015.1131809

Garcia-Pineda, O., Androulidakis, Y., Le Hénaff, M., Kourafalou, V., Hole, L. R., Kang, H. S., … DiPinto, L. (2020). Measuring oil residence time with GPS-drifters, satellites, and Unmanned Aerial Systems (UAS). *Marine Pollution Bulletin*, *150*(April 2019), 110644. https://doi.org/10.1016/j.marpolbul.2019.110644

Garcia-Pineda, O., Staples, G., Jones, C. E., Hu, C., Holt, B., Kourafalou, V., … Haces-Garcia, F. (2020). Classification of oil spill by thicknesses using multiple remote sensors. *Remote Sensing of Environment*, *236*. https://doi.org/10.1016/j.rse.2019.111421

Garron, J. (2019). Protocol for Using Unmanned Aircraft Systems (UAS) during an oil spill response or exercise. *University of Alaska Fairbanks Geophysical Institute Report*, *UAG-R 336*, 6. https://doi.org/doi.org/10.6084/m9.figshare.11788755.v2

Gholizadeh, M. H., Melesse, A. M., & Reddi, L. (2016). A comprehensive review on water quality parameters estimation using remote sensing techniques. *Sensors (Switzerland)*, *16*(8). https://doi.org/10.3390/s16081298

Gómez, C., & Green, D. R. (2017). Small unmanned airborne systems to support oil and gas pipeline monitoring and mapping. *Arab J Geosci*, *10*(202). https://doi.org/10.1007/s12517-017-2989-x

Goward, S., Masek, J., William, D., Irons, J., & Thompson, R. J. (2001). The Landsat Mission: Terrestrial Research and Applications for the 21st Century. *Remote Sensing of Environment*, *78*(1–2), 3–12. https://doi.org/https://doi.org/10.1016/S0034-4257(01)00262-0

Gowravaram, S., Tian, P., Flanagan, H., Goyer, J., & Chao, H. (2018). UAS-based Multispectral Remote Sensing and NDVI Calculation for Post Disaster Assessment. *2018 International Conference on Unmanned Aircraft Systems, ICUAS 2018*, 684–691. https://doi.org/10.1109/ICUAS.2018.8453314

Hann, R., Wenz, A., Gryte, K., & Johansen, T. A. (2017). Impact of atmospheric icing on UAV aerodynamic performance. *2017 Workshop on Research, Education and Development of Unmanned Aerial Systems (RED-UAS), Linkoping, 2017*, 66–71. https://doi.org/doi: 10.1109/RED-UAS.2017.8101645

Harada, K., Arai, I., Kashihara, S., & Fujikawa, K. (2020). A Performance Investigation of Thermal INfrared Camera and OPtical Camera for Searching Victims with an Unmanned Aerial Vehicle. *SenSys '20: Proceedings of the 18th Conference on Embedded Netwroked Sensor Systems*, 647–648.

Hruska, R., Mitchell, J., Anderson, M., & Glenn, N. F. (2012). Radiometric and geometric analysis of hyperspectral imagery acquired from an unmanned aerial vehicle. *Remote Sensing*, *4*(9), 2736–2752. https://doi.org/10.3390/rs4092736

Hua, L., & Shao, G. (2017). The progress of operational forest fire monitoring with infrared remote sensing. *Journal of Forestry Research*, *28*(2), 215–229. https://doi.org/10.1007/s11676-016-0361-8

Isser, M., Kranebitter, H., & Kofler, A. (2020). Rescue blankets hamper thermal imaging in search and rescue missions. *SN Applied Science*, *2*(1486). https://doi.org/https://doi.org/10.1007/s42452-020-03252-6

Jackisch, R., Madriz, Y., Zimmermann, R., Pirttijärvi, M., Saartenoja, A., Heincke, B. H., … Gloaguen, R. (2019). Drone-Borne Hyperspectral and Magnetic Data Integration: Otanmäki Fe-Ti-V Deposit in Finland. *Remote Sens.*, *11*, 2084.

Janzen, C. D., McCammon, M., Danielson, S. S. L., Weingartner, T., Statscewich, H., Page, E., & Heim, B. (2019). Innovative real-time observing capabilities for remote coastal regions. *Frontiers in Marine Science*, *6*(MAR), 1–8. https://doi.org/10.3389/fmars.2019.00176

Johnson, R., Smith, K., & Wescott, K. (2015). Unmanned Aircraft System (UAS) Applications to Land and Natural Resource Management. *Environmental Practice*, *17*(3), 170–177. https://doi.org/10.1017/S1466046615000216

Kabra, P., & Singh, B. (2019). Fire Detection Using Infrared Images for UAV-Based Forest Fire Surveillance. *International Research Journal of Engineering and Technology*, *6*(6).

Kawerak, Inc. (2013). Unalakleet Local Economic Development Plan 2014-2019. Retrieved from https://kawerak.org/wp-content/uploads/2018/02/Unalakleet.pdf

Kellenberger, B., Volpi, M., & Tuia, D. (2017). Fast animal detection in UAV images using convolutional neural networks. *IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Fort Worth, TX, 2017*, 866–869. https://doi.org/doi: 10.1109/IGARSS.2017.8127090

Kirsch, M., Lorenz, S., Zimmermann, R., Tusa, L., Möckel, R., Hödl, P., … Gloaguen, R. (2018). Integration of terrestrial and drone-borne hyperspectral and photogrammetric sensing methods for exploration mapping and mining monitoring. *Remote Sens.*, *10*, 1366.

Kontar, Y. Y., Bhatt, U. S., Lindsey, S. D., Plumb, E. W., & Thoman, R. L. (2015). Interdisciplinary approach to hydrological hazard mitigation and disaster response and effects of climate change on the occurrence of flood severity in central Alaska. *Proceedings of the International Association of Hydrological Sciences*, *369*, 13–17. https://doi.org/10.5194/piahs-369-13-2015

Kramar, V., & Määttä, H. (2018). UAV Arctic Challenges and the First Step: Printed Temperature Sensor. *Proceedings of the 23rd Conference of FRUCT Association*, 483–490. Retrieved from https://dl.acm.org/citation.cfm?id=3299971

Krause, D. J., Hinke, J. T., Perryman, W. L., Goebel, M. E., & LeRoi, D. J. (2017). An accurate and adaptable photogrammetric approach for estimating the mass and body condition of pinnipeds using an unmanned aerial system. *PLoS ONE*, *12*(11), 1–20. https://doi.org/10.1371/journal.pone.0187465

Lapeña-Rey, N., Blanco, J. A., Ferreyra, E., Lemus, J. L., Pereira, S., & Serrot, E. (2017). A fuel cell powered unmanned aerial vehicle for low altitude surveillance missions. *International Journal of Hydrogen Energy*, *42*(10), 6926–6940. https://doi.org/10.1016/j.ijhydene.2017.01.137

Lazogiannis, K., Vassilakis, E., Poulos, S. E., Kotsopoulos, S., Alexopoulos, J. D., & Alamanis, N. (2019). UAS-SfM as a cost-effective tool for coastal monitoring and management. *1st International Conference Design and Management of Port, Coastal and Offshore Works*, 135–139.

Lee, S., & Choi, Y. (2018). Comparison of topographic surveying results using a fixed-wing and a popular rotary-wing unmanned aerial vehicle (drone). *Tunn. Undergr. Space*, *26*, 24–31.

Leith, D., Sommerlatt, D., & Boundy, M. G. (2007). Passive sampler for PM10–2.5 aerosol. *Journal of the Air and Waste Management Association*, *57*(3), 332–336. https://doi.org/10.1080/10473289.2007.10465336

Li, S., Sun, D., Goldberg, M. D., Sjoberg, B., Santek, D., Hoffman, J. P., … Holloway, E. (2018). Automatic near real-time flood detection using Suomi-NPP/VIIRS data. *Remote Sensing of Environment*, *204*(March 2017), 672–689. https://doi.org/10.1016/j.rse.2017.09.032

Lima, M. C. F., Krus, A., Valero, C., Barrientos, A., Del Cerro, J., & Roldán-Gómez, J. J. (2020). Monitoring plant status and fertilization strategy through multispectral images. *Sensors*, *20*(2). https://doi.org/10.3390/s20020435

Linchant, J., Lisein, J., Semeki, J., Lejeune, P., & Vermeulen, C. (2015). Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges. *Mammal Review*, *45*(4), 239–252. https://doi.org/10.1111/mam.12046

Liu, D., Zhang, J., & Wang, X. (2016). Reference spectral signature selection using density-based cluster for automatic oil spill detection in hyperspectral images. *Optics Express*, *24*(7), 6521–6533. https://doi.org/10.1364/OE.24.007411

Liu, Yang, Li, L., Chen, W., Tian, W., & Hu, H. (2019). An experimental study on the aerodynamic performance degradation of a UAS propeller model induced by ice accretion process. *Experimental Thermal and Fluid Science*, *102*, 101–112. https://doi.org/https://doi.org/10.1016/j.expthermflusci.2018.11.008

Liu, Yi, Nie, J., Li, X., Ahmed, S. H., Lim, W. Y. B., & Miao, C. (2020). Federated Learning in the Sky: Aerial-Ground Air Quality Sensing Framework with UAV Swarms. *IEEE Internet of Things Journal*, *4662*(ii), 1–1. https://doi.org/10.1109/jiot.2020.3021006

Lort, M., Aguasca, A., López-Martínez, C., & Marín, T. M. (2018). Initial evaluation of SAR capabilities in UAV multicopter platforms. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *11*(1), 127–140. https://doi.org/10.1109/JSTARS.2017.2752418

Madden, M., Jordan, Thomas, Cotten, D., O'Hare, N., Pasqua, A., & Bernardes, S. (2015). The Future of Unmanned Aerial Systems for Monitoring Natural and Cultural Resources. *Photogrammetric Week*, 369–385. Retrieved from http://www.ifp.uni-stuttgart.de/publications/phowo15/350Madden.pdf%5Cnhttp://www.ifp.uni-stuttgart.de/publications/phowo15/

Madec, S., Baret, F., de Solan, B., Thomas, S., Dutartre, D., Jezequel, S., … Comar, A. (2017). High-Throughput Phenotyping of Plant Height: Comparing Unmanned Aerial Vehicles and Ground LiDAR Estimate. *Frontiers in Plant Science*, *8*. Retrieved from ttps://www.frontiersin.org/article/10.3389/fpls.2017.02002

Mader, D., Blaskow, R., Westfeld, P., & Weller, C. (2016). Potential of UAV-Based laser scanner and multispectral camera data in building inspection. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 1135–1142. https://doi.org/10.5194/isprsarchives-XLI-B1-1135-2016

Madsen, B., Treier, U., Zlinszky, A., Ucieer, A., & Normand, S. (2020). Detecting shrub encroachment in seminatural grasslands using UAS LiDAR. *Ecol Evol*, *10*, 4876– 4902. https://doi.org/https://doi.org/10.1002/ece3.6240

Manfreda, S., McCabe, M. F., Miller, P. E., Lucas, R., Madrigal, V. P., Mallinis, G., … Toth, B. (2018). On the use of unmanned aerial systems for environmental monitoring. *Remote Sensing*, *10*(4). https://doi.org/10.3390/rs10040641

Markon, C., S. Gray, M. Berman, L. Eerkes-Medrano, T. Hennessy, H. Huntington, J. Littell, M. McCammon, R. Thoman, and S. Trainor. (2018). Alaska. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1185–1241. doi: 10.7930/NCA4.2018.CH26

Marrero, L. B. (2019). Using Airborne and UAS Aerial Images to Evaluate Coastal Change and Impacts to Archaeological Sites Along Loíza's Coast, Puerto Rico. *International Geoscience and Remote Sensing Symposium (IGARSS)*, 9149–9152. https://doi.org/10.1109/IGARSS.2019.8899100

Matese, A., & Di Gennaro, S. F. (2018). Practical Applications of a Multisensor UAV Platform Based on Multispectral, Thermal and RGB High Resolution Images in Precision Viticulture. *Agriculture*, *8*(7). https://doi.org/https://doi.org/10.3390/agriculture8070116

Mishra, P. K., & Rai, A. (2020). Role of Unmanned Aerial Systems for Natural Resource Management. *Journal of the Indian Society of Remote Sensing*, *4*. https://doi.org/10.1007/s12524-020-01230-4

Moorhead, R., Hood, R., & Coffey, J. (2012). *Optimal Unmanned Aircraft Systems River Observing Strategy Workshop Summary Report*. Retrieved from https://uas.noaa.gov/Portals/5/Docs/Library/NOAA-UAS-River-Forecasting-Center-Workshop-2012-Report_Final.pdf

Murphy, R., Dufek, J., Sarmiento, T., Wilde, G., Xiao, X., Braun, J., … Sarkki, S. (2017). A method for using unmanned aerial vehicles for emergency investigation of single geo-hazards and sample applications of this method. *Natural Hazards and Earth System Sciences*, *7*(1), 1–5. https://doi.org/10.1109/ICELET.2013.6681648.

Native Village of Unalakleet. (2021). Retrieved from https://www.nativevillageofunalakleet.org/.

Ng, A. H.-M., Ge, L., Du, Z., Wang, S., & Ma, C. (2017). Satellite radar interferometry for monitoring subsidence induced by longwall mining activity using Radarsat-2, Sentinel-1 and ALOS-2 data. *Int. J. Appl. Earth Obs. Geoinf.*, *61*, 92–103.

Nicu, I. C., Stalsberg, K., Rubensdotter, L., Martens, V. V., & Flyen, A. C. (2020). Coastal erosion affecting cultural heritage in svalbard. A case study in hiorthhamn (adventfjorden)-An abandoned mining settlement. *Sustainability*, *12*(6), 1–21. https://doi.org/10.3390/su12062306

National Oceanic and Atmospheric Administration. (2021). Coastal Inundation Dashboard. Retrieved from https://tidesandcurrents.noaa.gov/inundationdb/.

Oceana and Kawerak, Inc. (2014). Bering Strait: Marine Life and Subsistence Use Data Synthesis.

Overbeck, J.R., K. Kennedy and R. Heim. (2017). Color-indexed elevation maps for flood-vulnerable coastal communities in western Alaska: Alaska Division of Geological & Geophysical Surveys Miscellaneous Publication 154 v. 2, 23 p., 36 sheets. https://doi.org/10.14509/29719

Papakonstantinou, A., Kavroudakis, D., Kourtzellis, Y., Chtenellis, M., Kopsachilis, V., Topouzelis, K., & Vaitis, M. (2019). Mapping Cultural Heritage in Coastal Areas with UAS: The Case Study of Lesvos Island. *Heritage*, *2*(2), 1404–1422. https://doi.org/10.3390/heritage2020089

Park, S., & Choi, Y. (2020). Applications of unmanned aerial vehicles in mining from exploration to reclamation: A review. *Minerals*, *10*(8), 1–32. https://doi.org/10.3390/min10080663

Parshin, A. V., Morozov, V. A., Blinov, A. V., Kosterev, A. N., & Budyak, A. E. (2018). Low-altitude geophysical magnetic prospecting based on multirotor UAV as a promising replacement for traditional ground survey. *Geo-Spat. Inf. Sci.*, *21*, 67–74.

Payne, C., Panda, S., & Prakash, A. (2018). Remote sensing of river erosion on the Colville river, North Slope Alaska. *Remote Sensing*, *10*(3). https://doi.org/10.3390/rs10030397

Perryman, W., & Lynn, M. (2002). Evaluation of nutritive condition and reproductive status of migrating gray whales (Eschrichtius robustus) based on analysis of photogrammetric data. *Journal of Research and Management*, *4*(2), 155 164.

Pignatti, S., Palombo, A., Pascucci, S., Santini, F., & Laneve, G. (2017). *Survey of the Pompeii (IT) Archaeological Regions with the Multi-Spectral Thermal Airborne TASI Data* (pp. 23–28.). pp. 23–28. Vienna: Copernicus Publications.

Rakha, T., & Gorodetsky, A. (2018). Review of Unmanned Aerial System (UAS) applications in the built environment: Towards automated building inspection procedures using drones. *Automation in Construction*, *93*(March), 252–264. https://doi.org/10.1016/j.autcon.2018.05.002

Raymond Hunt, E., & Stern, A. J. (2019). Evaluation of incident light sensors on unmanned aircraft for calculation of spectral reflectance. *Remote Sensing*, *11*(22). https://doi.org/10.3390/rs11222622

Ren, H., Zhao, Y., Xiao, W., & Hu, Z. (2019). A review of UAV monitoring in mining areas: current status and future perspectives. *International Journal of Coal Science and Technology*, *6*(3), 320–333. https://doi.org/10.1007/s40789-019-00264-5

Reuder, J. ., Jonassen, M. ., & Ólafsson, H. (2012). The small unmanned meteorological observer sumo: Recent developments and applications of a micro-uas for atmospheric boundary layer research. *Acta Geophys.*, *60*, 1454–1473.

Rhee, D. S., Kim, Y. Do, Kang, B., & Kim, D. (2018). Applications of unmanned aerial vehicles in fluvial remote sensing: An overview of recent achievements. *KSCE Journal of Civil Engineering*, *22*(2), 588–602. https://doi.org/10.1007/s12205-017-1862-5

Ross, M. R. V., Topp, S. N., Appling, A. P., Yang, X., Kuhn, C., Butman, D., … Pavelsky, T. M. (2019). AquaSat: A Data Set to Enable Remote Sensing of Water Quality for Inland Waters. *Water Resources Research*, *55*(11), 10012–10025. https://doi.org/10.1029/2019WR024883

Sankey, T., Donager, J., McVay, J., & Sankey, J. B. (2017). UAV lidar and hyperspectral fusion for forest monitoring in the southwestern USA. *Remote Sensing of Environment*, *195*, 30–43. https://doi.org/10.1016/j.rse.2017.04.007

Sasse, D. B. (2003). Job-Related Mortality of Wildlife Workers in the United States, 1937-2000. *Wildlife Society Bulletin*, *31*(4), 1015–1020.

Savage, S.H.; Levy, T.E.; Jones, I.W., J. (2012). Prospects and problems in the use of hyperspectral imagery for archaeological remote sensing: A case study from the Faynan copper mining district. *J. Archaeol. Sci.*, *39*, 407–420.

Seymour, A. C., Ridge, J. T., Rodriguez, A. B., Newton, E., Dale, J., & Johnston, D. W. (2018). Deploying Fixed Wing Unoccupied Aerial Systems (UAS) for Coastal Morphology Assessment and Management. *Journal of Coastal Research*, *34*(3), 704–717. https://doi.org/10.2112/JCOASTRES-D-17-00088.1

Shakhatreh, H., Sawalmeh, A. H., Al-fuqaha, A. L. A., Member, S., & Dou, Z. (2019). Unmanned Aerial Vehicles ( UAVs ): A Survey on Civil Applications and Key Research Challenges. *IEEE Access*, *7*, 48572–48634. https://doi.org/10.1109/ACCESS.2019.2909530

Shi, Y., Alex Thomasson, J., Murray, S. C., Ace Pugh, N., Rooney, W. L., Shafian, S., … Yang, C. (2016). Unmanned aerial vehicles for high-throughput phenotyping and agronomic research. *PLoS ONE*, *11*(7), 1–26. https://doi.org/10.1371/journal.pone.0159781

Song, W., Song, W., Gu, H., & Li, F. (2020). Progress in the remote sensing monitoring of the ecological environment in mining areas. *International Journal of Environmental Research and Public Health*, *17*(6). https://doi.org/10.3390/ijerph17061846

Spencer, B. F., Hoskere, V., & Narazaki, Y. (2019). Advances in Computer Vision-Based Civil Infrastructure Inspection and Monitoring. *Engineering*, *5*(2), 199–222. https://doi.org/10.1016/j.eng.2018.11.030

Starek, M. J., Cu, T., & Bridges, D. (2018). Evaluation of a Survey-Grade, Long-Range Uas Lidar System: a Case Study in South Texas, USA. *IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium*, 8765–8768. https://doi.org/doi: 10.1109/IGARSS.2018.8517340.

Stoll, J., & Moritz, D. (2013). Unmanned Aircraft Systems for Rapid Near Surface Geophysical Measurements. *Proceedings of the 75th EAGE Conference & Exhibition-WorkshopsLondon, UK; European Association of Geoscientists & Engineers*, 349–00062. Houten, the Netherlands.

Svejkovsky, J., Lehr, W., Muskat, J., Graettinger, G., & Mullin, J. (2012). Operational Utilization of Aerial Multispectral Remote Sensing during Oil Spill Response. *Photogrammetric Engineering & Remote Sensing*, *10*, 1089–1102. https://doi.org/doi.org/10.14358/PERS.78.10.1089

Thamm, H.-P., Ludwig, T., & Reuter, C. (2013). Design of a Process Modell for Unmanned Aerial Systems (UAS) in Emergencies. *Proceedings of the 10th International ISCRAM Conference*, (May), 478–487.

Tmušić, G., Manfreda, S., Aasen, H., James, M. R., Gonçalves, G., Ben-Dor, E., … McCabe, M. F. (2020). Current practices in UAS-based environmental monitoring. *Remote Sensing*, *12*(6). https://doi.org/10.3390/rs12061001

Topp, S. N., Pavelsky, T. M., Jensen, D., Simard, M., & Ross, M. R. V. (2020). Research trends in the use of remote sensing for inland water quality science: Moving towards multidisciplinary applications. *Water*, *12*(1), 1–34. https://doi.org/10.3390/w12010169

Turner, I., Harley, M., & Drummond, C. (2016). UAVs for Coastal Surveying. *Coastal Engineering*, *114*, 19–24. https://doi.org/https://doi.org/10.1016/j.coastaleng.2016.03.011

Turner, R. M., MacLaughlin, M. M., & Iverson, S. R. (2020). Identifying and mapping potentially adverse discontinuities in underground excavations using thermal and multispectral UAV imagery. *Eng. Geol.*, *266*, 105470.

United States Department of the Interior. (2020). 3 3 7 9 - Temporary Cessation of Non-Emergency Unmanned Aircraft Systems Fleet Operations.

United States Energy Information Administration. (2021a). Alaska State Profile and Energy Estimates. Retrieved from https://www.eia.gov/state/?sid=AK.

United States Energy Information Administration. (2021b). Energy Infrastructure with Active Storms and Other Hazards. Retrieved from https://www.eia.gov/special/disruptions/.

United States Energy Information Administration. (2021c) Flood Vulnerability Assessment Map. Retrieved from https://www.eia.gov/special/floodhazard/.

VanValkenburgh, P., Cushman, K. C., Butters, L. J. C., Vega, C. R., Roberts, C. B., Kepler, C., & Kellner, J. (2020). Lasers Without Lost Cities: Using Drone Lidar to Capture Architectural Complexity at Kuelap, Amazonas, Peru. *J. Field Archaeol.*, *45*, S75–S88.

Verfuss, U. K., Gillespie, D., Gordon, J., Marques, T. A., Miller, B., Plunkett, R., … Thomas, L. (2018). Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys. *Marine Pollution Bulletin*, *126*(May 2017), 1–18. https://doi.org/10.1016/j.marpolbul.2017.10.034

Vibhute, A., & K. Bodhe, S. (2012). Applications of Image Processing in Agriculture: A Survey. *International Journal of Computer Applications*, *52*(2), 34–40. https://doi.org/10.5120/8176-1495

Villa, T., Gonzalez, F., Miljevic, B., Ristovski, Z. D., & Morawska, L. (2016). An overview of small unmanned aerial vehicles for air quality measurements: Present applications and future prospectives. *Sensors (Switzerland)*, *16*(7), 12–20. https://doi.org/10.3390/s16071072

Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012). "Structure-from-Motion" photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*, *179*, 300–314. https://doi.org/10.1016/j.geomorph.2012.08.021

Wich, S., & Koh, L. P. (2012). Conservation drones. *GIM International*, *26*(11), 29–33.

Yan, J., Peng, Z., Hong, H., Chu, H., Zhu, X., & Li, C. (2018). Vital-SAR-Imaging With a Drone-Based Hybrid Radar System. *IEEE Transactions on Microwave Theory and Techniques*, *66*(12), 5852–5862. https://doi.org/10.1109/TMTT.2018.2874268

Yao, H., Qin, R., & Chen, X. (2019). Unmanned aerial vehicle for remote sensing applications - A review. *Remote Sensing*, *11*(12), 1–22. https://doi.org/10.3390/rs11121443

Yin, H., & Berger, C. (2017). Mastering data complexity for autonomous driving with adaptive point clouds for urban environments. *2017 IEEE Intelligent Vehicles Symposium (IV), Los Angeles, CA*, 1364–1371.

Yuan, C., Liu, Z., & Zhang, Y. (2017). Fire detection using infrared images for UAV-based forest fire surveillance. *2017 International Conference on Unmanned Aircraft Systems (ICUAS), Miami, FL, USA*, 567–572. https://doi.org/doi: 10.1109/ICUAS.2017.7991306

Zhi, S. D., Wei, Y. B., & Yu, Z. H. (2017). Air quality monitoring platform based on remote unmanned aerial vehicle with wireless communication. *ACM International Conference Proceeding Series*, *Part F1305*(July). https://doi.org/10.1145/3102304.3102339

Zhong, Y., Wang, X., Xu, Y., Wang, S., Jia, T., Hu, X., … Zhang, L. (2018). Mini-UAV-Borne Hyperspectral Remote Sensing: From Observation and Processing to Applications. *IEEE Geoscience and Remote Sensing Magazine*, *6*(4), 46–62. https://doi.org/10.1109/MGRS.2018.2867592Aasen, H., Burkart, A., Bolten, A., & Bareth, G. (2015). Generating 3D hyperspectral information with lightweight UAV snapshot cameras for vegetation monitoring: From camera calibration to quality assurance. *ISPRS Journal of Photogrammetry and Remote Sensing*, *108*, 245–259. https://doi.org/10.1016/j.isprsjprs.2015.08.002

# APPENDIX A - G

**APPENDIX A:** **UAS OPERATIONAL SOLUTIONS MATRIX**

**APPENDIX B:** **ONLINE TOOLS COMPARISON MATRIX**

**APPENDIX C:** **INTEGRATION/APPLICATION OF DATA INTO PLANNING MATRIX**

**APPENDIX D:** **ENVIRONMENTAL MONITORING WITH UNMANNED AERIAL VEHICLES: COST ESTIMATING & ANALYSIS**

**APPENDIX E:** **CONTRACTUAL CONSIDERATIONS - EXAMPLE OF PROFESSIONAL SERVICES LANGUAGE**

**APPENDIX F:** **UNALAKLEET FEASIBILITY STUDY PROJECT SURVEY (APRIL 2020)**

**APPENDIX G:** **ADDITIONAL RESOURCES ABOUT THE IMPACTS OF CLIMATE CHANGE ON ALASKA**

# APPENDIX A: UAS OPERATIONAL SOLUTIONS MATRIX

The UAS Operational Solutions Matrix synthesizes current commercial off the shelf sUAS payloads, aircraft, and post-processing software solutions available to address climate change impacts in coastal Alaska for four of the nine scientific study areas examined here; coastal erosion, flood preparation, water quality monitoring, infrastructure inspection. The solutions identified for the four science areas are translatable to the remaining five scientific study areas, as none of the technology described was designed for specific scientific data set collection, except for the in situ gas samplers used for air quality analyses. The UAS matrix is divided into low, medium, and high cost solutions of the proven sensor types that have been successfully miniaturized for use on UAVs, which UAVs can support them, along with processing software to support the collected data sets. Each of the UAS matrix solution blocks identifies both non-US made and US made aircraft, sensors, post-processing solutions, and an estimate of the minimum amount of training that would be required for successful flight using those systems. Training requirements are based on the amount of time and number of trainers that would be required to train a novice UAS pilot on the operation of the aircraft, payload, and post-processing software identified solution block. Operational details about the aircraft, sensors, and software are included as are comparative estimates for the same data collected by a vendor using either a sUAS or manned aircraft system.

# UAS OPERATIONAL SOLUTIONS MATRIX

| Scientific Study Areas | Identification of Technology Needs & Costs — Technology Needs/Cost (Low) <$5000 | | | | | | | Identification of Technology Needs & Costs — Technology Needs / Cost (Medium) $5000-$10000 | | | | | | | | Identification of Technology Needs & Costs — Technology Needs / Cost (High) >$10000 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Unmanned Aircraft* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* |
| **Coastal Erosion Monitoring** *[Objectives: Identification and quantification of erosion-based coastal changes; identification and monitoring of erosion-prone coastal areas]* | | | | | | | | | | | | | | | | | | | | | | | |
| **Coastal Erosion Monitoring** | | | | | | | | | | | | | | | | | | | | | | | |
| *Optical* | N/A | Time-lapse camera | VLC[1] | high | none | low | **$186-$600** | DGGS contracted ground-based shoreline monitoring | typically 14°F~113°F | Time-lapse camera mounted in a fixed location | N/A | high | none | none | $14,050/year | DJI Matrice 100 *quadcopter* ($4000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Zenmuse Z30 ($3000) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 2.13 MP/inch | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $4000+$3000+$3500+$2750/yr = **$13,250** (with training $32,250) |
| | N/A | Emery rod technique | N/A | high | none | low | **$295** | Non-DGGS contracted ground-based shoreline monitoring | typically 14°F~113°F | Time-lapse camera mounted in a fixed location | N/A | high | none | none | $5,900/year | DJI Matrice 200 *quadcopter* ($9462) | 2.4000-2.4835 GHz; 5.725-5.850 GHz;-4F-122F (-20C-50C) | Zenmuse X5S ($1900) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 20.8 Megapixels/inch; at aspect ratio 4:3, 5280×3956 (140 cm x 105 cm), at aspect ratio 16:9, 5280×2970 (140 cm x 79 cm); 4K (105 cm x 5.7 cm) at 60 fps, 5.2K at 30 fps | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $9462+$1900+$3500+$2750/yr = **$17,612** (with training $36,612) |
| | DJI Mavic Pro ($2000) | EO sensor[2] | Adobe Photoshop + Adobe Premiere Pro (on-line updates; $492/yr) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+492/yr = **$2492** (with training $9492) | Autel Evo ($1300) | 2.4000-2.4835 GHz; 32°F ~ 104°F (0°C ~ 40°C) | EO sensor | Pix4D ($4990) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $1300+$4990 = **$6290** (with training $13,290) | Sentaero v2 VTOL *VTOL* ($29,000) | | Sony A7RIII (inluded with UAV) | | (Sony) 1 cm x 1 cm GSD from 400' AGL; (MicaSense) 8 cm x 8 cm GSD from 400' AGL | heavy (Aerial Applications processing); minimal (in-house) | low-med (aircraft only, 2 trainers, 80 hours/10-days, $14,000 & Aerial Applications processing $?); high (aircraft & in-house processing, 3 trainers, 120 hours/15-days, $28,500) | $29000+$3500+$2750/y = **$35,250** (with training $49,250 and $63,750 respectively) |
| | Phantom 4 Pro v2 ($2000) | EO sensor | Adobe Photoshop + Adobe Premiere Pro (on-line updates; $492/yr) | 20 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+$492/yr = **$2492** (with training $9492) | DJI Mavic Pro ($2000) | 2.4000-2.4835 GHz; 22°F ~ 104°F (-10°C ~ 40°C) | EO sensor | DroneDeploy ($3600), Pix4D ($4990), Drone2Map (ESRI free tribal license) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | $2000+$3600/$4990 per year = **$5600/$6990** (With training $19,600/$20,990) | 3DR H520-G *hexcopter* ($6000) | 2.4000-2.4835 GHz; 14F-104F (-10C-40C) | E90 | Pix4D ($4990); Site Scan (Unk $builit on Pix4D) | 20 MP/inch; 4k (105 cm x 5.7 cm) video | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $6000+$4990 = **$10,990** (with training $29,990) |
| | Autel Evo ($1300) | EO sensor | Drone2Map (ESRI free tribal license) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | **$1300** (with training $15,300) | | | | | | | | | Matrice 600 *hexcopter* ($5000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Revolution 120 ($40000); Zenmuse X5S ($1900) | GlobalMapper; PPK software | (R120) 120,000 pts/sec (200 pts/m2 at 100 m AGL, 3.8 cm x 3.8 cm at 50 m AGL); (X5S) 20.8 MP/inch; at aspect ratio 4:3, 5280×3956 (140 cm x 105 cm), at aspect ratio 16:9, 5280×2970 (140 cm x 79 cm); 4K (105 cm x 5.7 cm) at 60 fps. 5.2K at 30 fps | unknown | Extra high (2 weeks pilot trainers, 4 weeks data trainers, $39500) | $5000+$40000+$1900+$1200+$2000 = **$50,100** (with training $89,600) |
| *LiDAR* | X | X | X | | | X | X | | | | | | | | | Aerial Applications (contractor) | | | | | Heavy (on-line up and download) to zero (hard drive transfer) | none | **$40,000/trip** |
| | | | | | | | | | | | | | | | | LiDAR USA (Contractor) | | | | | unknown | none | **$50,000-150,000 (3 trips)** |
| | | | | | | | | | | | | | | | | Helicopter based survey ($1000/hr, including 2 hrs each way from Nome) | 14F-104F (-10C-40C) | Revolution 120 ($40000); Sony A7RIII ($3000) | GlobalMapper; PPK software | (R120) 120,000 pts/sec (200 pts/m2 at 100 m AGL, 3.8 cm x 3.8 cm at 50 m AGL); (Sony) 1 cm x 1 cm GSD from 400' AGL | none | high (2 trainers, 120 hours/15-days, $19,000) | $43,000 one time sensor cost, $5000/data collection, $19,000 one time training cost = $67,000 intial collection an dtraining and ~$6000/collection subsequent efforts |

| Scientific Study Areas | Identification of Technology Needs & Costs | | | | | | | Identification of Technology Needs & Costs | | | | | | | | Identification of Technology Needs & Costs | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Technology Needs/Cost (Low) <$5000 | | | | | | | Technology Needs / Cost (Medium) $5000-$10000 | | | | | | | | Technology Needs / Cost (High) >$10000 | | | | | | | |
| | *Unmanned Aircraft* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* |
| **Flood Preparation (river & sea)** *[Objectives: Identification of areas prone to flooding, new and old]* | | | | | | | | | | | | | | | | | | | | | | | |
| **Flood Preparation (river & sea)** | | | | | | | | | | | | | | | | | | | | | | | |
| *Optical* | N/A | Time-lapse camera (stationary) | VLC[1] | | No | low | **$186-$600** | DJI Mavic Pro ($2000) | 2.4000-2.4835 GHz; 22°F ~ 104°F (-10°C ~ 40°C) | EO sensor | DroneDeploy ($3600)/Pix4D ($4990) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | $2000+$3600/yr or $4990= **$5600/$6990** (with training $19,600/$20,990 | DJI Matrice 100 *quadcopter* ($4000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Zenmuse Z30 ($3000) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 2.13 MP/inch | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $4000+$3000+$3500+$2750/yr = **$13,250** (with training $32,250) |
| | DJI Mavic Pro ($2000) | EO sensor[2] | Adobe Photoshop + Adobe Premiere Pro | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+492/yr = **$2492** (with training $9492) | | | | | | | | | DJI Matrice 200 *quadcopter* ($9462) | 2.4000-2.4835 GHz; 5.725-5.850 GHz;-4F-122F (-20C-50C) | Zenmuse X5S ($1900) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | at aspect ratio 4:3, 5280×3956 (140 cm x 105 cm) at aspect ratio 16:9, 5280×2970 (140 cm x 79 cm) | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $9462+$1900+$3500+$2750/yr = **$17,612** (with training $36,612) |
| | Phantom 4 Pro v2 ($2000) | EO sensor | Adobe Photoshop + Adobe Premiere Pro | 20 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+492/yr = **$2492** (with training $9492) | | | | | | | | | 3DR H520-G *hexcopter* ($6000) | 2.4000-2.4835 GHz; 14F-104F (-10C-40C) | E90 | Pix4D ($4990); Site Scan (Unk $builit on Pix4D) | 20 MP/inch; 4k (105 cm x 5.7 cm) video | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $6000+$4990 = **$10,990** (with training $29,990) |
| | Autel Evo ($1300) | EO sensor | Drone2Map (ESRI free tribal license) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | **$1300** (with training $15,300) | | | | | | | | | | | | | | | | |
| *LiDAR* | X | X | X | | | X | X | | | | | | | | | Matrice 600 *hexcopter* ($5000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Revolution 120 ($40000); Zenmuse X5S ($1900) | GlobalMapper; PPK software | (R120) 120,000 pts/sec (200 pts/m2 at 100 m AGL, 3.8 cm x 3.8 cm at 50 m AGL); (X5S) 20.8 MP/inch; at aspect ratio 4:3, 5280×3956 (140 cm x 105 cm), at aspect ratio 16:9, 5280×2970 (140 cm x 79 cm); 4K (105 cm x 5.7 cm) at 60 fps. 5.2K at 30 fps | | Extra high (2 weeks pilot trainers, 4 weeks data trainers, $39500) | $5000+$40000+$1900+$1200+$2000 = **$50,100** (with training $89,600) |
| | | | | | | | | | | | | | | | | LiDAR Contractor | | | | | | | **>$150,000** |
| | | | | | | | | | | | | | | | | Helicopter based survey ($1000/hr, including 2 hrs each way from Nome) | 14F-104F (-10C-40C) | Revolution 120 ($40000); Sony A7RIII ($3000) | GlobalMapper; PPK software | (R120) 120,000 pts/sec (200 pts/m2 at 100 m AGL, 3.8 cm x 3.8 cm at 50 m AGL); (Sony) 1 cm x 1 cm GSD from 400' AGL | none | high (2 trainers, 120 hours/15-days, $19,000) | $43,000 one time sensor cost, $5000/data collection, $19,000 one time training cost = $67,000 intial collection an dtraining and ~$6000/collection subsequent efforts |

| Scientific Study Areas | Identification of Technology Needs & Costs | | | | | | | Identification of Technology Needs & Costs | | | | | | | | Identification of Technology Needs & Costs | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Technology Needs/Cost (Low) <$5000 | | | | | | | Technology Needs / Cost (Medium) $5000-$10000 | | | | | | | | Technology Needs / Cost (High) >$10000 | | | | | | | |
| | *Unmanned Aircraft* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* |
| **Infrastructure Monitoring** *[Objectives: Identify current state of key NVU infrastructure]* | | | | | | | | | | | | | | | | | | | | | | | |
| **Infrastructure Monitoring** | | | | | | | | | | | | | | | | | | | | | | | |
| *Optical and Optical+Infrared sensors* | N/A | Time-lapse camera (stationary) | VLC[1] | | No | low | **$186-$600** | DJI Mavic Pro ($2000) | 2.4000-2.4835 GHz; 22°F ~ 104°F (-10°C ~ 40°C) | EO sensor | DroneDeploy ($3600)/Pix4D ($4990) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | $2000+$3600/yr (or $4990)= **$5600 ($6990)** | DJI Matrice 100 *quadcopter* ($4000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Zenmuse Z30 ($3000), FLIR Vue Pro ($3700) | FLIR Tools, Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 2.13 MP/inch | minimal (initial software download) | high (3 trainers, 120 hours/15-days, $28,500) | $4000+$3000+$3700+$295+$3500+$2750/yr = **$17,245** (with training $45,745) |
| | DJI Mavic Pro ($2000) | EO sensor[2] | Adobe Photoshop + Adobe Premiere Pro (on-line updates; $492/yr) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+492/yr = **$2492** (with training $9492) | Mavic 2 Enterprise ($3600) | 2.4000-2.4835 GHz; 22°F ~ 104°F (-10°C ~ 40°C) | EO sensor, IR sensor[3] | DroneDeploy ($3600)/Pix4D ($4990) | IR (160x120 pixels or 4 cm x 3.2 cm); EO (4k video as 105 cm x 5.7 cm; at aspect ratio 4:3, 4056x3040 pixels or 107 cm x 80 cm, at aspect ratio 16:9, 4056x2280 pixels or 107 cm x 60 cm) | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | $3600+$3600/yr (or $4990) = **$7495 ($8885)** | DJI Matrice 200 *quadcopter* ($9462) | 2.4000-2.4835 GHz; 5.725-5.850 GHz;-4F-122F (-20C-50C) | Zenmuse X5S ($1900), FLIR Vue Pro ($3700) | FLIR Tools, Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | at aspect ratio 4:3, 5280×3956 (140 cm x 105 cm) at aspect ratio 16:9, 5280×2970 (140 cm x 79 cm) | minimal (initial software download) | high (3 trainers, 120 hours/15-days, $28,500) | $9462+$1900+$3700+$3500+$2750/yr = **$21,312** (with training $49,812) |
| | Phantom 4 Pro v2 ($2000) | EO sensor | Adobe Photoshop + Adobe Premiere Pro (on-line updates; $492/yr) | 20 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+492/yr = **$2492** (with training $9492) | | | | | | | | | 3DR H520-G *hexcopter* ($6000) | 2.4000-2.4835 GHz; 14F-104F (-10C-40C) | FLIR Vue Pro ($3700) | Pix4D ($4990); Site Scan (Unk $builit on Pix4D) | 20 MP/inch; 4k (105 cm x 5.7 cm) video | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $6000+$3700+$4990 = **$14,690** (with training $33,690) |
| | Autel Evo ($1300) | EO sensor | Drone2Map (ESRI free tribal license) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | **$1300** (with training $15,300) | | | | | | | | | | | | | | | | |
| *Multispectral sensors* | x | x | x | | x | x | x | x | | x | x | | x | x | x | DJI Matrice 100 *quadcopter* ($4000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | MicaSense ($5000) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 8 cm/pixel at 400 ft AGL | minimal (initial software download) | high (3 trainers, 120 hours/15-days, $28,500) | $4000+$5000+$3500+$2750/yr = **$15,250** (with training $43,750) |
| | | | | | | | | | | | | | | | | DJI Matrice 200 *quadcopter* ($9462) | 2.4000-2.4835 GHz; 5.725-5.850 GHz;-4F-122F (-20C-50C) | MicaSense ($5000) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 8 cm/pixel at 400 ft AGL | minimal (initial software download) | high (3 trainers, 120 hours/15-days, $28,500) | $9462+$5000+$3500+$2750/yr = **$20,712** (with training $49,212) |
| | | | | | | | | | | | | | | | | Sentaero v2 VTOL *VTOL* ($29,000) | 2.4000-2.4835 GHz; 30F-104F (-1C-40C) | MicaSense ($5000) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 8 cm/pixel at 400 ft AGL | minimal | high (3 trainers, 120 hours/15-days, $28,500) | $29000+$5000+$3500+$2750/yr = **$40,250 (**with training $68,750) |
| *LiDAR* | x | x | x | | x | x | x | x | | x | x | | x | x | x | Matrice 600 *hexcopter* ($5000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Revolution 120 ($40000); Zenmuse X5S ($1900) | GlobalMapper; PPK software | (R120) 120,000 pts/sec (200 pts/m2 at 100 m AGL, 3.8 cm x 3.8 cm at 50 m AGL); (X5S) 20.8 MP/inch; at aspect ratio 4:3, 5280×3956 (140 cm x 105 cm), at aspect ratio 16:9, 5280×2970 (140 cm x 79 cm); 4K (105 cm x 5.7 cm) at 60 fps. 5.2K at 30 fps | unknown | Extra high (2 weeks pilot trainers, 4 weeks data trainers, $39500) | $5000+$40000+$1900+$1200+$2000 = **$50,100** (with training $78,600) |
| | | | | | | | | | | | | | | | | LIDAR contractor | | | | | | | |

| Scientific Study Areas | Identification of Technology Needs & Costs — Technology Needs/Cost (Low) <$5000 | | | | | | | Identification of Technology Needs & Costs — Technology Needs / Cost (Medium) $5000-$10000 | | | | | | | | Identification of Technology Needs & Costs — Technology Needs / Cost (High) >$10000 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Unmanned Aircraft* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* | *Unmanned Aircraft* | *Operating Range* | *Hardware* | *Software (Download vs DVD)* | *Resolution/ Accuracy* | *Internet Requirements* | *Training Requirements* | *Cost* |
| **Water Quality Monitoring** *[Objectives: Measure the spectral characteristics of water and pollutants to determine quality]* | | | | | | | | | | | | | | | | | | | | | | | |
| **Water Quality Monitoring** | | | | | | | | | | 0 | | | | | | | | | | | | | |
| *Optical sensors* | N/A | Time-lapse camera (stationary) | VLC[1] | | No | low | **$186-$600** | DJI Mavic Pro ($2000) | 2.4000-2.4835 GHz; 22°F ~ 104°F (-10°C ~ 40°C) | EO sensor | DroneDeploy ($3600)/Pix4D ($4990) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | $2000+$3600/yr (or $4990)= **$5600 ($6990)** | DJI Matrice 100 *quadcopter* ($4000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Zenmuse Z30 | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 2.13 MP/inch | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $4000+$1138+$3500 +$2750/yr = **$11,388** (with training $30,388) |
| | DJI Mavic Pro ($2000) | EO sensor[2] | Adobe Photoshop + Adobe Premiere Pro (on-line updates; $492/yr) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+492 /yr = **$2492** (with training $9492) | | | | | | | | | DJI Matrice 200 *quadcopter* ($9462) | 2.4000-2.4835 GHz; 5.725-5.850 GHz;-4F-122F (-20C-50C) | Zenmuse X5S | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 4:3, 5280×3956 (140 cm x 105 cm) 16:9, 5280×2970 (140 cm x 79 cm) | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $9462+$1900+$3500 +$2750/yr = **$17,612** (with training $36,612) |
| | Phantom 4 Pro v2 ($2000) | EO sensor | Adobe Photoshop + Adobe Premiere Pro (on-line updates; $492/yr) | 20 MP/inch | minimal (initial software download) | low (2 trainers, 40 hours/5-days, $7000) | $2000+492 /yr = **$2492** (with training $9492) | | | | | | | | | 3DR H520-G *hexcopter* ($6000) | 2.4000-2.4835 GHz; 14F-104F (-10C-40C) | E90 | Pix4D ($4990); Site Scan (Unk $builit on Pix4D) | 20 MP/inch; 4k (105 cm x 5.7 cm) video | minimal (initial software download) | med-high (3 trainers, 80 hours/10-days, $19000 ) | $6000+$4990 = **$10,990** (with trianing $29,990) |
| | Autel Evo ($1300) | EO sensor | Drone2Map (ESRI free tribal license) | 4K video (105 cm x 5.7 cm); 12 MP/inch | minimal (initial software download) | low-med (2 trainers, 80 hours/10-days, $14,000) | **$1300** (with training $15,300) | | | | | | | | | Sentaero v2 VTOL *VTOL* ($29,000) | 2.4000-2.4835 GHz; 30F-104F (-1C-40C) | Sony A7RIII (inluded with UAV) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | (Sony) 1 cm GSD from 400' AGL; (MicaSense) 8 cm GSD from 400' AGL | heavy (Aerial Applications processing); minimal (in-house) | minimal (Aerial Applications processing); high (3 trainers, 120 hours/15-days, $28,500) | $29000+$3500+$2750/y = **$35,250** (with training $63,750) |
| *Multispectral sensors* | x | x | x | | x | x | x | x | | x | x | | x | x | x | DJI Matrice 100 *quadcopter* ($4000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | MicaSense ($5000) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | 8 cm/pixel (GSD) at 400' AGL | minimal (initial software download) | high (3 trainers, 120 hours/15-days, $28,500) | $4000+$5000+$3500 +$2750/yr = **$15,250** (with training $43,750) |
| | | | | | | | | | | | | | | | | Sentaero v2 VTOL *VTOL* ($29,000) | 2.4000-2.4835 GHz; 30F-104F (-1C-40C) | Sony A7RIII (inluded with UAV); MicaSense ($5000) | Metashape Pro ($3500; Download), ArcGIS Pro ($2750/yr*; On-line access &/or License check-out) | (Sony) 1 cm GSD from 400' AGL; (MicaSense) 8 cm GSD from 400' AGL | heavy (Aerial Applications processing); minimal (in-house) | minimal (Aerial Applications processing); high (3 trainers, 120 hours/15-days, $28,500) | $29000+$5000+$3500+$2750/y = **$40,250** (with training $68,750) |
| *Hyperspectral sensors* | | | | | | | | | | | | | | | | Matrice 600 *hexcopter* ($5000) | 2.4000-2.4835 GHz; 5.725-5.850 GHz; 14F-104F (-10C-40C) | Specim AFX10 ($64200) | Proprietary software ($2500) | 640 spectral pixels/1024 spatial pixels (17 spectral cm x 27 spectral cm) | unknown | Extra high (2 weeks pilot trainers, 4 weeks data trainers, $39500) | $5000+$64136+$2500 = $**71,000** (with training $110,500) |
| *In situ water samplers (for laboratory analyses)* | | | | | | | | | | | | | | | | Alta X *quadcopter* ($20,000) | 2.4 GHz; -4F-113F (-20C-40C) | Specim AFX10 ($64200) | Proprietary software ($2500) | 640 spectral pixels/1024 spatial pixels (17 spectral cm x 27 spectral cm) | unknown | Extra high (2 weeks pilot trainers, 4 weeks data trainers, $39500) | $20000+$64136+$2500 = **$87000** (with training $126,500) |
| | | | | | | | | | | | | | | | | Helicopter based survey ($1000/hr, including 2 hrs each way from Nome) | 14F-104F (-10C-40C) | Specim AFX10 ($64200) | Proprietary software ($2500) | 640 spectral pixels/1024 spatial pixels (17 spectral cm x 27 spectral cm) | unknown | high (2 trainers, 120 hours/15-days, $19,000) | $67,000 one time sensor cost, $5000/data collection, $19,000 one time training cost = $90,700 intial collection and training and ~$6000/collection subsequent efforts |

This matrix assumes all folks have Part 107 training an certification already.

[1] VLC is a video playing program; free

[2] EO Sensor is an electro-optical sensor that creates still images and video in the visible spectrum, e.g. camera

[3] IR sensor is infrared sensor, long-wave, 7.5-13 µm

[4] low (2 trainers, 40 hours/5-days, $7000)

[5] low-med (2 trainers, 80 hours/10-days, $14,000)

[6] med-high (3 trainers, 80 hours/10-days, $19000 )

[7] high (3 trainers, 120 hours/15-days, $28,500)

[8] Extra high (2 weeks pilot trainers, 4 weeks data trainers, $39500)

# APPENDIX B: ONLINE TOOLS COMPARISON MATRIX

Recognizing that establishing a UAS program in a community might be too expensive yet data is needed for planning purposes, the Model Forest Policy Program researched whether online climate tools exist that provide data somewhat comparable to data collected locally by the use of drones and sensors. This research resulted in the creation of the following matrix with samples of existing online tools that could help communities gather climate-related data (eg., historical, real-time, and projected). The final matrix is organized primarily by the nine scientific study areas.

## NVU Project Online Tool Comparison Matrix Final (Initial Focus - Coastal Alaska)

| Description | General Information | | | | | | |
|---|---|---|---|---|---|---|---|
| Column Headers | Tool Title / Name of Tool | Link | Organization/Sponsor | Tool Form | All Scientific Study Area(s) | Tool Theme | Description |
| Definition | Enter the tool title. | The URL or link where the tool can be accessed. | The organization and/or sponsor of the tool. | In what form is the tool? (e.g. Web based, spreadsheet, handbook, other). | Identify applicable Scientific Study Areas:<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. Water Quality Monitoring<br>5. Cultural & Historical Site Identification & Monitoring<br>6. Extractable Resource Identification (Mapping) & Monitoring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring<br>9. Air Quality Monitoring | What is the main focus of the tool (e.g. temperature, ice fluctuation, sea level rise, snowpack, precipitation, forest planning, permafrost, etc.) | Brief 2-3 sentence description of the purpose of the tool. |
| **1. Coastal Erosion Monitoring** | | | | | | | |
| | **Unalakleet Water Level (Tide) Gauge** | https://tidesandcurrents.noaa.gov/waterlevels.html?id=9468333 | NOAA - Tide & Currents | Web based | Coastal Erosion; Flood Preparation, Infrastructure | Observed water levels | User can specifiy the time frame of data; this example reflects a single graph of 2 days of observed water levels |
| | **Alaska Division of Geological & Geophysical Surveys (AKDGGS)** | https://dggs.alaska.gov/ | Alaska Division of Geological & Geophysical Surveys (AKDGGS) | Main Web page for multiple tools and resources. | Coastal Erosion; Flood Preparation, Infrastructure (Primary areas) | Sea level rise, permafrost, ice and snow | AKDGGS' main website from which you can visit multiple sites. |
| | **Alaska Shoreline Change Tool** | http://maps.dggs.alaska.gov/shoreline/#-16253081:9110399:3 | Alaska Division of Geological & Geophysical Surveys (AKDGGS) | Web platform for the Shoreline Tool. | Coastal Erosion; Flood Preparation, Infrastructure | Shoreline change | This interactive tool displays historic and predicted shoreline position throughout Alaska. Users can explore the coasts of the state to see where shoreline has been in the past, and where it will be in the future. |
| | **Coastal Hazards - Coastal Flooding and Erosion Around the State** | https://dggs.alaska.gov/hazards/coastal/ | Alaska Division of Geological & Geophysical Surveys (AKDGGS) | Web platform for Coastal Hazards. | Coastal Erosion; Flood Preparation, Infrastructure | Coastal flooding and erosion | Website provides coastal flood and erosion hazards data and infomation that ranges from historical to projected. Good summary of what is provided at: http://dggs.alaska.gov/webpubs/dggs/ic/text/ic068.pdf. |
| | **Coastal Change Analyses for Western Alaska: Interactive Map; also called AK Coastal Change Viewer** | https://portal.aoos.org/old/coastalchange#module-metadata/f3ae63c7-e1dc-480e-bcc5-7eea36ceafd0/db42d756-3e9b-42ff-9a2c-91d780683d90 | Western Alaska Landscape Conservation Cooperative (LCC) | Web Interactive Mapping | Coastal Erosion; Infrastructure Monitoring | Coastal erosion, habitat loss and gain due to deposition | Tool displays various maps and images documenting coastal change along the west coast of Alaska, from Kotzebue to Kodiak Island, reaching inland approximately 2 km. The analyses provide important baseline information on the distribution and magnitude of landscape changes from erosion and aggradation (deposition) over 41 years. The maps document changes in the shape and extent of land, as well as in coastal features such as spits, barrier islands, estuaries, tidal guts, and lagoons. |
| | **Alaska Coastal Profile Tool (ACPT)** | http://maps.dggs.alaska.gov/acpt/ | Alaska Division of Geological & Geophysical Surveys | Web Interactive map based tool | Coastal Erosion | Beach elevation profile measurements | Interactive, map-based tool that enables access to beach elevation profile measurements collected throughout Alaska since the 1960s. |
| | **Alaska ShoreZone Mapping & Imagery** | https://alaskafisheries.noaa.gov/mapping/szflex/; https://www.fisheries.noaa.gov/alaska/habitat-conservation/alaska-shorezone; http://www.shorezone.org/ | NOAA | Web based aerial view [images/videos] & physical & biological data | Coastal Erosion; Infrastructure Monitoring; Oil Spill & Habitat Models | AK coastal physical & biological conditions | This standardized system catalogs both geomorphic (the landscape and other natural features of the Earth's surface) and biological (living organisms) resources at mapping scales of better than 1:10,000. The high-resolution, attribute-rich dataset is a useful tool for extrapolation of site data over broad spatial ranges and creating a variety of habitat models. |
| | **Quarterly Climate Impacts and Outlook for Alaska and Northwestern Canada** | https://www.drought.gov/drought/climate-outlook/Alaska%20and%20Northwestern%20Canada | The National Drought Resilience Partnership (NDRP) comprises seven federal agencies | Downloadable short report | Flood Preparation; Water Quality; Plant Community; Wildlife; Cultural Site Monitoring | Temperature & precipitation | Provides a summary of the region's weather and climate impacts from the previous quarter as well as outlooks for temperature and precipitation for the coming quarter. |
| | **Stakes for Stakeholders: Community-Based Erosion Monitoring** | http://dggs.alaska.gov/webpubs/dggs/ic/text/ic084.pdf | Alaska Division of Geological & Geophysical Surveys | Downloadable guide | Coastal Erosion | Coastal erosion | A step-by-step guide for documenting shoreline change in your community. This booklet provides comprehensive instructions for implementing three community-based shoreline monitoring systems, with all instructions designed to be completed by local residents. Tips for selecting monitoring sites, instructions for site installation and data collection, and all necessary materials are explained in a step-by-step format. By building an understanding of long-term shoreline change, Alaskans will be better prepared to respond and adapt to impacts to their public health, safety, infrastructure, and well-being. |
| ng | **Understanding and Evaluating Erosion Problems** | https://www.commerce.alaska.gov/web/Portals/4/pub/Understanding&EvaluatingErosionPub.pdf | Alaska Department of Commerce, Community, and Economic Development | Downloadable guide | Erosion | River and coastal AK erosion | This handbook is intended to assist Alaskan property owners and communities in understanding and evaluating erosion problems and alternative solutions. The fundamental principles and means of controlling erosion are presented to enable users to understand potential solutions. |
| | **NWS Alaska Sea Ice Program (ASIP)** | https://www.weather.gov/afc/ice | National Weather Service/NOAA | Zoomable maps | Coastal Erosion; Flood Preparation | Ice conditions | Many easy to use features including [1] maps that you can zoom into specific sites, [2] regional information called Standard Ice Analysis and Forecast Maps: maps of where the ice is concentrated, stage of the ice [old to new, free] [3] Sea Ice Advisory: 5 day ice forecast, [4] 3 month Sea Ice Outlook: break up patterns of the ice in different regions ["However, the overall retreat in the Beaufort Sea is about as extreme as our analyses have shown in the last 20 years."]; freeze up predictions for the coming months; [5] Additional Satellite Resources: images of sea ice from March 2019. |
| | **The National Assessment of Storm-Induced Coastal Change Hazards** | https://www.usgs.gov/centers/spcmsc/science/national-assessment-storm-induced-coastal-change-hazards?qt-science_center_objects=0#qt-science_center_objects | USGS | Web | Coastal Erosion; Flood Preparation | Coasts | The National Assessment of Storm-Induced Coastal Change Hazards component of the National Assessment of Coastal Change Hazards project focuses on understanding the magnitude and variability of extreme storm impacts on sandy beaches. The overall objective is to improve real-time and scenario-based predictions of coastal change to support management of coastal infrastructure, resources, and safety. |
| | **Encountering Environmental Hazards on Alaska's Coasts** | https://seagrant.uaf.edu/topics/environmental-hazards-alaskas-coasts/flooding-erosion/ | NOAA | Website | Coastal Erosion; Flood Preparation | Erosion, flood | Overview, resources on AK flooding and erosion. |

| General Information (continued) | Flowchart Components (Conditionally Formatted) - Organizational Filter | | | | | Found on Toolkit |
|---|---|---|---|---|---|---|
| **Main Tool Outputs** | **Data (Complexity) (Low, Medium, High)** | **Geographic Area (G1, G2, G3, G4)** | **[Time frame covered] Published Date (P1, P2, P3, P4, P5)** | **Required Time to Review (RT1, RT 2, RT3, RT4)** | **Bandwidth (B1, B2, B3, B4)** | **U.S. Climate Resilience Toolkit** |
| What are the final products? Map, graph, narrative, shapefile, etc.? (For example, a map might be the primary output, however, the tool may also allow the user to do comparisons, scenarios or generate reports.) | **Low** - Specific to one Scientific Study Area & low complexity<br>**Medium** - Relevant to more than one Study Area & moderate complexity<br>**High** - Need high level of knowledge to interpret information. | **1.** Specific to one of Alaska's 5 Geographic Regions (Far North, Interior, Southwest, Southcentral, Southeast).<br>**2.** Alaska Statewide<br>**3.** National/ International<br>**4.** National/ Local Specific Site. | **1.** Real-time Data<br>**2.** 2011 - 2020<br>**3.** 2000-2010<br>**4.** 1990-2000<br>**5.** <1990 | **1.** 0-30 mins. **2.** 30-60 mir | **1.** Text /Graph (0-5 MB)<br>**2.** Text & Video (5 - 10 MB)<br>**3.** Text & Video, Map (10 -20 MB)<br>**4.** Graphical User Interface (GUI) (Consideration:Delete GUI option; more the norm, than not.) | Is tool found on U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) or not? If yes, insert the url. |
| Graph downloadable as PDF, JPEG, PNG, or CSV. | Medium | G4 / Unalakleet specific. | P1 | RT2 | B1 | https://toolkit.climate.gov/tool/noaa-tides-currents |
| Multiple Outputs | Medium | G2 (Primary focus is Alaska) | P2 | RT4 | B4 (B3) | Multiple AKDGGS sites are. |
| Digital geospatial data (shapefiles metadata); multiple data layers available (topo, street map, satelite). http://dggs.alaska.gov/pubs/id/29504 | High | G4/ Can focus on Unalakleet specific. | P2 (2015) | RT3 | B3 (B4) | https://toolkit.climate.gov/tool/alaska-community-inundation-maps; https://toolkit.climate.gov/tool/alaska-shoreline-change-tool |
| As with other Alaska DGGS sites, multiple outputs available from site. | Medium | G2 (Primary focus is Alaska) | P2 (2015) | RT4 | B3 (B4) | Links to various AKDGGS site found on Toolkit. This specific one not found. |
| Map; underlying data is here: https://www.sciencebase.gov/catalog/item/5a4db553e4b0d05ee8c4d539 | High | G1 (Western Alaska) | P2 (2016) | RT4 | B3 | https://toolkit.climate.gov/tool/coastal-change-analyses-western-alaska-interactive-map; same as https://toolkit.climate.gov/tool/alaska-coastal-change-viewer |
| http://dggs.alaska.gov/metadata/DDS7.faq.html; Geospatial_Data_Presentation_Form: delimited text files | High | G2 (Alaska Coasts) | P2 (2014) | RT4 | B3 | https://toolkit.climate.gov/tool/alaska-coastal-profile-tool |
| https://www.fisheries.noaa.gov/alaska/habitat-conservation/alaska-shorezone; "Images, videos, and maps of Alaska's coastline imagery and data in mapped regions of Alaska can be viewed, queried, and downloaded at the NOAA ShoreZone website. Video on how to use its/supportive materials: https://www.fisheries.noaa.gov/alaska/habitat-conservation/alaska-shorezone. | Medium | G4 (OR, WA, AK) | P1? | RT3 | B3 | https://toolkit.climate.gov/tool/alaska-shorezone-coastal-mapping-and-imagery |
| Quaterly Report as PDF Powerpoint | Medium | G2 AK & NW Canada | P1 | RT1 | B1 | https://toolkit.climate.gov/tool/alaska-and-northwestern-canada-quarterly-climate-impacts-and-outlook |
| 39 page PDF | Low | G3 (Coastal) | P2 (2019) | RT2 | B1 | https://toolkit.climate.gov/tool/stakes-stakeholders-community-based-erosion-monitoring |
| 63 page PDF | Low | G2 | P2 (updated 2013) | RT2 | B1 | https://toolkit.climate.gov/tool/understanding-and-evaluating-erosion-problems |
| Can view maps. No downloadable product but can save images by printing the web page. | Medium | G2 | P1, forecasting | RT1 | B2 - B3 | |
| Assessments, forecasts | Medium | G3 (Coastal) | P1 | RT2 | B3 | |
| Tools and resources | Medium | G2 | P1, P2 | Rt1 | B2 - B3 | |

| Description | General Information | | | | | | |
|---|---|---|---|---|---|---|---|
| Column Headers | Tool Title / Name of Tool | Link | Organization/Sponsor | Tool Form | All Scientific Study Area(s) | Tool Theme | Description |
| Definition | Enter the tool title. | The URL or link where the tool can be accessed. | The organization and/or sponsor of the tool. | In what form is the tool? (e.g. Web based, spreadsheet, handbook, other). | Identify applicable Scientific Study Areas:<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. Water Quality Monitoring<br>5. Cultural & Historical Site Identification & Monitoring<br>6. Extractable Resource Identification (Mapping) & Monitoring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring<br>9. Air Quality Monitoring | What is the main focus of the tool (e.g. temperature, ice fluctuation, sea level rise, snowpack, precipitation, forest planning, permafrost, etc.) | Brief 2-3 sentence description of the purpose of the tool. |
| **2. Flood Preparation Monitoring** | | | | | | | |
| | **Alaska Current Water Conditions** | https://www.usgs.gov/centers/water-dashboard/surface?state=ak | USGS | Website | Flood Preparation; Water Quality Monitoring | Current water conditions | Surface water, water quality, ground water. |
| | **Western AK Flood Inundation Maps** | http://dggs.alaska.gov/pubs/id/29719 | Alaska Division of Geological & Geophysical Surveys | Downloadable color indexed maps | Flood Preparation | Flood preparation; infrastructure monitoring | These color-indexed maps, freely available for download in PDF format, merge best-available datasets into a tool that can streamline communication about forecasted water levels, local elevations, and potentially impacted infrastructure in advance of storm events that may cause coastal flooding. These maps are not designed to function as flood inundation maps, but to serve as a tool to communicate about elevations in at-risk coastal communities until true inundation mapping can be completed.<br><br>Pilot work to test the usefulness of this map format is available for five communities: Kivalina, Shishmaref, Golovin, Shaktoolik, and Unalakleet. The map series was updated in 2017 using recent elevation data at Golovin, Shaktoolik, and Unalakleet, with additional maps created for Wales, Brevig Mission, Teller, Nome, Nunam Iqua, Hooper Bay, Tununak, and Toksook Bay. |
| | **Local Environmental Observer (LEO) Network** | http://www.leonetwork.org/en/#lat=38.49457&lng=43.38323&zoom=7 | Alaska Native Tribal Health Consortium (ANTHC) | Web based network | All Scientific Study Areas:<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. Water Quality Monitoring<br>5. Cultural & Historical Site Identification & Monitoring<br>6. Extractable Resource Identification (Mapping) & Monitoring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring<br>9. Air Quality Monitoring | AK observations in all scientific study areas | In 2009, the Alaska Native Tribal Health Consortium (ANTHC) established the Center for Climate and Health to help describe connections between climate change, environmental impacts, and health effects. In 2012, LEO Network was launched as a tool to help the tribal health system and local observers to share information about climate and other drivers of environmental change.LEO is a network of local observers and topic experts who share knowledge about unusual animal, environment, and weather events. With LEO, you can connect with others in your community, share observations, raise awareness, and find answers about significant environmental events. You can also engage with topic experts in many different organizations and become part of a broader observer community. |
| | **Coastal Inundation Dashboard** | https://tidesandcurrents.noaa.gov/inundationdb_info.html | NOAA | Web | Coastal Erosion Monitoring; Flood Preparation Monitoring, | Inundation | Coastal Inundation Dashboard (https://tidesandcurrents.noaa.gov/inundationdb/) provides real-time water levels, 48-hour forecasts of water levels and historic flooding information at a majority of coastal water level stations operated by the National Ocean Service (NOS) Center for Operational Oceanographic Products & Services (CO-OPS). The product features both a map based view where users can see which stations across the U.S. may be flooding, and a more detailed station view where real-time water levels and historical data for a specific location are highlighted. |
| | **River Observation Map** | https://www.weather.gov/ajk/OurOffice-Hydro | NOAA | Web | Flood Preparation | Flood preparation; infrastructure monitoring | The National Weather Service (NWS) is the primary source for hydrologic watches, warnings, and advisories for the United States. Local NWS offices are responsible for issuing: Flood Watches, Flash Flood Watches, Flood Warnings, Flash Flood Warnings, and Flood Advisories. These products can and do emphasize different hydrologic issues depending on geographic area, land use, time of year, as well as other meteorological and non-meteorological factors. |
| | **Quarterly Climate Impacts and Outlook** | https://toolkit.climate.gov/tool/alaska-and-northwestern-canada-quarterly-climate-impacts-and-outlook | NOAA | Downloadable pdfs | Coastal Erosion Monitoring; Flood Preparation Monitoring; Infrastructure Monitoring; Water Quality Monitoring | Temperature and precipitation | The Quarterly Climate Impacts and Outlook for Alaska and Northwestern Canada provides a summary of the region's weather and climate impacts from the previous quarter as well as outlooks for temperature and precipitation for the coming quarter. Since the fall of 2016, the Outlook product for Alaska has been issued with coordination and input from northwestern Canada. The Outlook includes all of Alaska and the Canadian provinces of the Yukon, Northwest Territories, and northern British Columbia. |
| | **Climate at a Glance** | https://www.ncdc.noaa.gov/cag/divisional/mapping/50/pcp/201901/60/value | NOAA | Web based | Flood Preparation | Temperature and precipitation | This is an easy to use mapping tool where user can ask for specific region, state, county, city, time frame, data on temperature, precipitation, time scale, and a map will be generated. This would be useful to see changes in both over time and how that has impacted warming seas, river erosion, flooding, wildlife and plant communities. Certain time frames do not generate data. |
| | **Daily Streamflow Conditions** | https://waterdata.usgs.gov/ak/nwis/rt | USGS | Web based | Flood Preparation | Stream Flow | Current data typically are recorded at 15- to 60-minute intervals, stored onsite, and then transmitted to USGS offices every 1 to 4 hours. |
| | **SURGEDAT** | http://surge.srcc.lsu.edu/about.html | NOAA, SCIPP | Maps, data on web | Flood Preparation; Coastal Erosion; Infrastructure | storm surge | The world's storm surge data center - This site has now archived the location and height of more than 700 tropical surge events around the world since 1880. |
| | **Barrow Sea Ice Thickness and Sea Level Webcam and Radar** | https://seaice.alaska.edu/gi/observatories/barrow_sealevel/ | University o f Alaska Fairbanks (UAF) | Tools not functioning | Flood Preparation | Flood preparation; infrastructure monitoring | Water Depth, Ice Thickness, Snow Depth, and Air Temperature. The site contains a coastal webcam and radar, a sea ice mass balance, sea level station, and forecasts for early summer break-up of landfast ice. Ice coring and ice thickness profiles are obtained near each site. |

| General Information (continued) | Flowchart Components (Conditionally Formatted) - Organizational Filter | | | | | Found on Toolkit |
|---|---|---|---|---|---|---|
| **Main Tool Outputs** | **Data (Complexity) (Low, Medium, High)** | **Geographic Area (G1, G2, G3, G4)** | **[Time frame covered] Published Date (P1, P2, P3, P4, P5)** | **Required Time to Review (RT1, RT 2, RT3, RT4)** | **Bandwidth (B1, B2, B3, B4)** | **U.S. Climate Resilience Toolkit** |
| What are the final products? Map, graph, narrative, shapefile, etc.? (For example, a map might be the primary output, however, the tool may also allow the user to do comparisons, scenarios or generate reports.) | **Low** - Specific to one Scientific Study Area & low complexity<br>**Medium** - Relevant to more than one Study Area & moderate complexity<br>**High** - Need high level of knowledge to interpret information. | **1.** Specific to one of Alaska's 5 Geographic Regions (Far North, Interior, Southwest, Southcentral, Southeast).<br>**2.** Alaska Statewide<br>**3.** National/ International<br>**4.** National/ Local Specific Site. | **1.** Real-time Data<br>**2.** 2011 - 2020<br>**3.** 2000-2010<br>**4.** 1990-2000<br>**5.** <1990 | **1.** 0-30 mins. **2.** 30-60 mir | **1.** Text /Graph (0-5 MB)<br>**2.** Text & Video (5 - 10 MB)<br>**3.** Text & Video, Map (10 -20 MB)<br>**4.** Graphical User Interface (GUI) (Consideration:Delete GUI option; more the norm, than not.) | Is tool found on U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) or not? If yes, insert the url. |
| Discharge, stage | Low | G2 | P1 | RT1 | B1 | |
| Free downloadable PDF | Low | G1 | P2 | RT1 | B1 | https://toolkit.climate.gov/tool/alaska-community-inundation-maps |
| View/add observations in many topic areas | Medium | G3 | P2 | RT1 | B2 (Map seems to load quickly.) | |
| Maps, analytic tool | Medium | G3 | P1 | RT2 | B3 | |
| Map printable | Low | G1 [not Norton Bay] | P1 | RT1 | B1 | |
| PDF short reports | Medium | G3, Canada | P2 | RT1 | B1 | https://toolkit.climate.gov/tool/alaska-and-northwestern-canada-quarterly-climate-impacts-and-outlook |
| Downladable maps and data tables | Low | G1,G2, G3, G4 | P5, P2 | RT1 | B2 | https://toolkit.climate.gov/tool/climate-glance |
| Summaries, tables or graphs | Low | G2 | P1 | RT1 | B1 | |
| Maps, data base, web | Medium | G3 | P1 - P5 | RT2 | B2 (Map seems to load quickly.) | |
| Onsite not functioning since 2016 | Low | G1 | P2 | RT1 | B3 | https://toolkit.climate.gov/tool/barrow-sea-ice-thickness-and-sea-level-webcam-and-radar |

| Description | General Information | | | | | | |
|---|---|---|---|---|---|---|---|
| Column Headers | Tool Title / Name of Tool | Link | Organization/Sponsor | Tool Form | All Scientific Study Area(s) | Tool Theme | Description |
| Definition | Enter the tool title. | The URL or link where the tool can be accessed. | The organization and/or sponsor of the tool. | In what form is the tool? (e.g. Web based, spreadsheet, handbook, other). | Identify applicable Scientific Study Areas:<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. Water Quality Monitoring<br>5. Cultural & Historical Site Identification & Monitoring<br>6. Extractable Resource Identification (Mapping) & Monitoring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring<br>9. Air Quality Monitoring | What is the main focus of the tool (e.g. temperature, ice fluctuation, sea level rise, snowpack, precipitation, forest planning, permafrost, etc.) | Brief 2-3 sentence description of the purpose of the tool. |
| **3. Infrastructure Monitoring** | | | | | | | |
| | **Transportable Array** | http://www.usarray.org/Alaska | Earth Scope | Web information | Infrastructure | Seismic activity | The EarthScope Transportable Array (TA) is a dense network of state-of-the-art seismic stations that, from 2004-2015, migrated across the contiguous 48 states recording the high-quality data needed to map the structure of the earth beneath North America; usarray.org/researchers/obs/transportable. |
| | **Energy Infrastructure with Active Storms and Other Hazards** | https://www.eia.gov/special/disruptions/ | US Energy Information Administration | Web based | Infrastructure Monitoring | Infrastructure monitoring | The map is intended to help identify potential threats to energy infrastructure from significant storms and other weather events, flooding, and wildfires. Use the Layers/Legend panel to access all the available map layers. |
| | **US Energy Mapping System** | https://www.eia.gov/state/?sid=AK | US Energy Information Administration | Web based | Infrastructure Monitoring; Flood Preparation | Infrastructure monitoring | This interactive map shows various aspects of U.S energy infrastructure, including energy conversion sites, transmission pathways, and various energy reserves. The set of map layers includes fossil energy resources as well as geothermal, biomass, solar, and wind resources. Map layers also show coal mines, power plants, oil and gas refining and processing plants, market hubs, pipelines, and electrical transmission networks.Profiles for each state and territory provide easy-to-understand graphs on the sources and uses of the region's energy. |
| | **Climate Ready Infrastructure and Strategic Sites Protocol (CRISSP)** | https://glslcities.org/initiatives/municipal-climate-adaptation/crissp/ | AECOM, the City of Gary and University of Michigan's Great Lakes Integrated Science and Assessment office (GLISA) | Downloadable guide and risk matrix pdf | Flood Preparation Monitoring; Infrastructure M | Infrastructure monitoring | The CRISSP guides your municipality through a step-by-step process to assemble your CRISSP team, gather relevant information on hazards and climate data, identify municipal infrastructure, facilities and sites located in extreme weather hazard zones, and perform a vulnerability assessment on them. A key aspect of the CRISSP is a helpful, easy to use Risk Matrix tool that takes users through a series of critical questions to assess the vulnerability of municipal facilities, sites or infrastructure. |
| | **Flood Vulnerability Assesment Map** | https://www.eia.gov/special/floodhazard/ | US Energy Information Administration | Web based | Infrastuctue Monitoring; Flood Preparation | Infrastuctue monitoring, Flood Preparation | This interactive map gives users a way to identify which assets of the U.S. energy sector are vulnerable to flooding hazards. The map shows flood hazard information from the Federal Emergency Management Administration along with energy infrastructure layers from the U.S. Energy Information Administration. State, county, city, and private-sector planners can use the map to assess which energy infrastructure assets are vulnerable to rising sea levels, storm surges, and flash flooding. Note that flood hazard layers must be zoomed in to street level before they become visible. For a full set of energy infrastructure layers, refer to the U.S. Energy Mapping System - https://toolkit.climate.gov/tool/us-energy-mapping-system. |
| **4. Water Quality Monitoring** | | | | | | | |
| | **AK Streamflow** | https://waterdata.usgs.gov/ak/nwis/rt | USGS | web | Flood Preparation; Water Quality | Stream flow | Current data typically are recorded at 15- to 60-minute intervals, stored onsite, and then transmitted to USGS offices every 1 to 4 hours, depending on the data relay technique used. |
| | **USGS Water-Quality Data for Alaska** | https://waterdata.usgs.gov/ak/nwis/qw | USGS | Web | Water Quality Monitoring | water quality data | The USGS collects and analyzes chemical, physical, and biological properties of water, sediment and tissue samples from across the Nation. |
| | **WaterQualityWatch -- Continuous Real-Time Water Quality of Surface Water in the United States** | https://waterwatch.usgs.gov/wqwatch/map?state=ak&pcode=00010 | USGS | Web | Water Quality Monitoring | Water quality monitoring | The "Real-time" map tracks short-term changes (over several hours) of water quality [temperature, condition, discharge, etc.] |
| | **AK Monitoring & Assessment Program** | https://dec.alaska.gov/water/water-quality/monitoring/ | AK Dept Environmental Quality Conservation Division of Water | Web | Water Quality Monitoring | Water quality monitoring | The mission of DEC's Division of Water is to improve and protect the quality of all Alaskan waters. One way the Division carries out this mission is to monitor and report on water quality. |
| | **Imiq** | http://arcticlcc.org/projects/imiq/ | Arctic Landscape Conservation Cooperative (LCC) | Web | Coastal Erosion Monitoring; Flood Preparation Monitoring; Infrastructure Monitoring; Water Quality Monitoring; Plant Community Monitoring | Hydrology, climate, soils | The Imiq Hydroclimate Database houses hydrologic, climatologic, and soils data collected in Alaska and Western Canada from the early 1900s to the present. This database unifies and preserves numerous data collections that have, until now, been stored in field notebooks, on desktop computers, as well as in disparate databases.The Imiq Data Portal provides a snapshot of available hydroclimate data – a map-based view of where , what , and when data have been obtained. |
| | **The Water Quality Portal (WQP)** | https://www.waterqualitydata.us/ | Cooperative service sponsored by USGS, EPA, and the National Water Quality Monitoring Council (NWQMC) | Web | Water Quality Monitoring | Water quality monitoring | The Water Quality Portal (WQP) is a cooperative service sponsored by the United States Geological Survey (USGS), the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC). It serves data collected by over 400 state, federal, tribal, and local agencies. |

| General Information (continued) | Flowchart Components (Conditionally Formatted) - Organizational Filter | | | | | Found on Toolkit |
|---|---|---|---|---|---|---|
| Main Tool Outputs | Data (Complexity)<br>(Low, Medium, High) | Geographic Area (G1, G2, G3, G4) | [Time frame covered]<br>Published Date<br>(P1, P2, P3, P4, P5) | Required Time to Review<br>(RT1, RT 2, RT3, RT4) | Bandwidth<br>(B1, B2, B3, B4) | U.S. Climate Resilience Toolkit |
| What are the final products? Map, graph, narrative, shapefile, etc.? (For example, a map might be the primary output, however, the tool may also allow the user to do comparisons, scenarios or generate reports.) | **Low** - Specific to one Scientific Study Area & low complexity<br>**Medium** - Relevant to more than one Study Area & moderate complexity<br>**High** - Need high level of knowledge to interpret information. | **1.** Specific to one of Alaska's 5 Geographic Regions (Far North, Interior, Southwest, Southcentral, Southeast).<br>**2.** Alaska Statewide<br>**3.** National/ International<br>**4.** National/ Local Specific Site. | **1.** Real-time Data<br>**2.** 2011 - 2020<br>**3.** 2000-2010<br>**4.** 1990-2000<br>**5.** <1990 | **1.** 0-30 mins. **2.** 30-60 mir | **1.** Text /Graph (0-5 MB)<br>**2.** Text & Video (5 - 10 MB)<br>**3.** Text & Video, Map (10 -20 MB)<br>**4.** Graphical User Interface (GUI)<br>(Consideration:Delete GUI option; more the norm, than not.) | Is tool found on U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) or not? If yes, insert the url. |
| | | | | | | |
| Transportable Array data is publicly available via the IRIS Data Management Center; usarray.org/researchers/data. | Low | G2, G3 | P1, P2 | RT2 | B3 | |
| Printable map | Low | G1- G4 | P1, P2 | RT2 | B3 | |
| Map, tables | Medium | G2, G3 | P2 | RT2 | B3 | https://toolkit.climate.gov/tool/us-energy-mapping-system |
| Matrix | Medium | G3, G4 | P1, P2 | RT4 | B1 | https://toolkit.climate.gov/tool/climate-ready-infrastructure-and-sensitive-sites-protocol-crissp |
| Map, tables | Medium | G2, G3 | P2 | RT2 | B3 | https://toolkit.climate.gov/tool/energy-infrastructure-flood-vulnerability |
| | | | | | | |
| Summary tables, graphs | Low | G2 | P1 | RT1 | B1, B3 | |
| Data Summaries (Will need a station name or Lat/Long, most likely to generat report.) | Medium | G2, G3 | P1 | RT2 | B1 | |
| Visual map | Low | G2 | P1 | RT1 | B1 | |
| AK map, surveys, bioassessments | Low | G1, G2 | P1, P2 | RT2 | B1 | |
| Users can submit a custom data query, specifying variable of interest, geographic bounds, and time step. Imiq will aggregate and export data records from multiple sources in a common format, with full metadata records that provide information about the source data. | High | G2 | P2, P5 | RT3 | B2 - B3 | |
| Download data in Excel, CSV, TSV, KML formats | Low | G3 | P2 | RT3 | B3 | |

| Description | General Information | | | | | | |
|---|---|---|---|---|---|---|---|
| Column Headers | Tool Title / Name of Tool | Link | Organization/Sponsor | Tool Form | All Scientific Study Area(s) | Tool Theme | Description |
| Definition | Enter the tool title. | The URL or link where the tool can be accessed. | The organization and/or sponsor of the tool. | In what form is the tool? (e.g. Web based, spreadsheet, handbook, other). | Identify applicable Scientific Study Areas:<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. Water Quality Monitoring<br>5. Cultural & Historical Site Identification & Monitoring<br>6. Extractable Resource Identification (Mapping) & Monitoring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring<br>9. Air Quality Monitoring | What is the main focus of the tool (e.g. temperature, ice fluctuation, sea level rise, snowpack, precipitation, forest planning, permafrost, etc.) | Brief 2-3 sentence description of the purpose of the tool. |
| **5. Cultural & Historical Site Identification & Monitoring** | | | | | | | |
| | **The Alaska Heritage Resources Survey (AHRS)** | http://dnr.alaska.gov/parks/oha/ahrs/ahrs.htm | Alaska Department of Natural Resources | Restricted Access Data Repository | Cultural & Historic Site Identification & Monitoring | Cultural & Historic Site Identification & Monitoring | Data repository with information on over 45,000 reported cultural resources (archaeological sites, buildings, structures, objects or locations, etc.), from prehistoric to modern, and some paleontological sites within the State of Alaska. |
| | **The State Historic Preservation Office Monitoring Guidelines** | http://dnr.alaska.gov/parks/oha/hpseries/hp15.pdf | Alaska Department of Natural Resources | PDF | Cultural & Historic Site Identification & Monitoring | Monitoring | The State Historic Preservation Office (SHPO) occasionally recommends that an undertaking subject to Section 106 review be archaeologically monitored. PDF contains these guidelines. |
| | **Cultural Resources On the Bureau of Land Management Public Lands: An Assessment and Needs Analysis** | https://forum.savingplaces.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=6597c637-744e-f734-522a-350011df2a25 | Bureau of Land Management | PDF | Cultural & Historic Site Identification & Monitoring | Monitoring | Discussion document on the enormous scope of the cultural resources to be found on the BLM public lands continues to dwarf the staff and funds allocated to manage them. |
| **6. Extractable Resource Identification (Mapping) & Monitoring** | | | | | | | |
| | **Alaska Resource Data File (ARDF)** | https://ardf.wr.usgs.gov/index.php | USGS | online data | Extractable Resource Id Mapping and Monitoring | Extractable resources | Descriptions of mines, prospects, and mineral occurrences in the Alaska Resource Data File (ARDF) are published for individual U.S. Geological Survey 1:250,000-scale quadrangles in Alaska (see accompanying map or table) as USGS Open-File Reports and are available for downloading from this site. These descriptions are divided into fields which describe each mine, prospect, or mineral occurrence. The records in the database are generally for metallic mineral commodities only but also may include certain high value industrial minerals such as barite and rare earth elements. Common industrial minerals such as sand and gravel, crushed stone, and limestone and energy minerals such as peat, coal, oil and gas are not included in this database. |
| | **Mineral Resources Online Spatial Data** | https://mrdata.usgs.gov/general/map-ak.html | USGS | Online data | Extractable Resource Id Mapping and Monitoring | Extractable resources | Interactive maps and downloadable data for regional and global Geology, Geochemistry, Geophysics, and Mineral Resources. This interface emphasizes scientific data in Alaska. |
| **7. Wildlife Surveys** | | | | | | | |
| | **Alaska Fisheries Science Center Surveys in the Arctic: 2019 Preliminary Findings** | https://www.fisheries.noaa.gov/alaska/science-data/alaska-fisheries-science-center-surveys-arctic-2019-preliminary-findings | NOAA | Web based research information | Wildlife Surveys | We collect a variety of biological, ecological, and environmental data to learn about the health and size of populations of fish, crabs, whales, seals and other species in the key areas where they feed, breed, and grow. | *We collect a variety of biological, ecological, and environmental data to learn about the health and size of populations of fish, crabs, whales, seals and other species in the key areas where they feed, breed, and grow.* |
| | **Refuges, Sanctuaries, Critical Habitat Areas & Wildlife Ranges** | http://www.adfg.alaska.gov/index.cfm?adfg=maps.refugeboundaries&disclaimer=read | Alaska Department of Fish and Game | Web based KLM files of different refuges | Wildlife Surveys | Habitat protection | KLM files + link to individual critical areas |
| | **Management & Harvest Reports** | http://www.adfg.alaska.gov/index.cfm?adfg=librarypublications.wildlifemanagement | AK Dept of Fish and Game | Reports | Wildlife Surveys | Wildlife Management | Management & Harvest Reports; Moose, caribou, brown and black bear, deer, sheep, goat, elk, muskox, bison, wolves/furbearers. |
| **8. Plant Community Monitoring** | | | | | | | |
| | **The Alaska Vegetation Classification** | https://doi.org/10.2737/PNW-GTR-286 | US Forest Service | Web report/PDF | Plant Community Monitoring | Categorizes existing vegetation | The Alaska vegetation classification presented here is a comprehensive, statewide system that has been under development since 1976. The classification is based, as much as possible, on the characteristics of the vegetation itself and is designed to categorize existing vegetation, not potential vegetation. A hierarchical system with five levels of resolution is used for classifying Alaska vegetation. The system, an agglomerative one, starts with 888 known Alaska plant communities, which are listed and referenced. At the broadest level of resolution, the system contains three formations-forest, scrub, and herbaceous vegetation . |
| | **Alaska Vegetation and Wetland Composite** | https://accscatalog.uaa.alaska.edu/dataset/alaska-vegetation-and-wetland-composite | University of Alaska Anchorage (UAA) | Data, Reports, | Plant Community Monitoring | The Alaska Vegetation and Wetland Composite (AKVWC) represents the best-available data derived from 28 regional land cover maps that have been developed within the last 31 years. | The statewide distribution of wetland, deepwater, and upland habitats presented here represents the first effort to map wetlands in accordance with the national wetland classification system at medium-scale resolution for Alaska. |
| | **Plant Community Ecology** | https://accs.uaa.alaska.edu/vegetation/plant-community-ecology/ | Alaska Center for Conservation Science. | Web data base, Plot Maps | Plant Community Monitoring | Vegetation Plots | Alaska Vegetation Plots Database. |

| General Information (continued) | Flowchart Components (Conditionally Formatted) - Organizational Filter | | | | | Found on Toolkit |
|---|---|---|---|---|---|---|
| **Main Tool Outputs** | **Data (Complexity) (Low, Medium, High)** | **Geographic Area (G1, G2, G3, G4)** | **[Time frame covered] Published Date (P1, P2, P3, P4, P5)** | **Required Time to Review (RT1, RT 2, RT3, RT4)** | **Bandwidth (B1, B2, B3, B4)** | **U.S. Climate Resilience Toolkit** |
| What are the final products? Map, graph, narrative, shapefile, etc.? (For example, a map might be the primary output, however, the tool may also allow the user to do comparisons, scenarios or generate reports.) | **Low** - Specific to one Scientific Study Area & low complexity<br>**Medium** - Relevant to more than one Study Area & moderate complexity<br>**High** - Need high level of knowledge to interpret information. | **1.** Specific to one of Alaska's 5 Geographic Regions (Far North, Interior, Southwest, Southcentral, Southeast).<br>**2.** Alaska Statewide<br>**3.** National/ International<br>**4.** National/ Local Specific Site. | **1.** Real-time Data<br>**2.** 2011 - 2020<br>**3.** 2000-2010<br>**4.** 1990-2000<br>**5.** <1990 | **1.** 0-30 mins. **2.** 30-60 mir | **1.** Text /Graph (0-5 MB)<br>**2.** Text & Video (5 - 10 MB)<br>**3.** Text & Video, Map (10 -20 MB)<br>**4.** Graphical User Interface (GUI) (Consideration:Delete GUI option; more the norm, than not.) | Is tool found on U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) or not? If yes, insert the url. |
| | Starting new definitions here | | | | | |
| The AHRS began as a map-based system that used USGS topographic maps at 1:250,000 and 1:63,360 (1" = 1 mile) scales. AHRS site numbers are still assigned by USGS Quad today. Each cultural resource is given an individual AHRS site number consisting of a three-letter designation (tri-graph) relating to the USGS quadrangle map on which the cultural resource is located, followed by a unique sequential number within that quadrangle (i.e., SIT--00010 is the AHRS number for the tenth cultural resource recorded within the Sitka quadrangle). For each individual cultural resource, the AHRS has a record with the site name, description of the physical remains, data on the site's location (using the NAD83 datum). | Low | G2 | P5 (up to modern) | Restricted access; unable to estimate. | B1 (Most likely.) | |
| PDF | Low | G2 | N/A | RT1 | B1 | |
| PDF | Low | G3 | P3 (Written 2006) | RT2 | B1 | |
| Data base, multiple formats | Low | G2 | P2 | RT2 - RT3 | B2 - B3 | |
| Maps, downloadable data | Low | G2 | P5 (Site also includes more recent data as well.) | RT2 - RT4 | B2 - B3 | |
| Web site | Low | G2 | P2 | RT3 | B1 | |
| KLM (Google Earth) files; pdf - an option | Low | G2 | P1 | RT2 | B2 - B3 | |
| Reports | Low | G2 | P2 | RT1 | B1 | |
| Report | Low | G2 | P5 | RT2 - RT4 | B1 | |
| Map, composite, report and viewer guide | Low | G2 | P2 | RT2 - RT3 | B1, B3 | |
| ACCS is actively involved in the crafting of the mid- and lower-level vegetation units (plant associations) of the National Vegetation Classification (NVC) as they apply to arctic and boreal Alaska. Plant associations are assemblages of species that respond similarly to environmental conditions such as climate, geology, topography, hydrology, and soil. ACCS provides a provisional list of plant associations and their attendant conservation status ranks that have been formally described for Alaska. | Low | G2 | P2 | RT2 | B1, B3 | |

| Description | General Information | | | | | | |
|---|---|---|---|---|---|---|---|
| Column Headers | Tool Title / Name of Tool | Link | Organization/Sponsor | Tool Form | All Scientific Study Area(s) | Tool Theme | Description |
| Definition | Enter the tool title. | The URL or link where the tool can be accessed. | The organization and/or sponsor of the tool. | In what form is the tool? (e.g. Web based, spreadsheet, handbook, other). | Identify applicable Scientific Study Areas:<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. Water Quality Monitoring<br>5. Cultural & Historical Site Identification & Monitoring<br>6. Extractable Resource Identification (Mapping) & Monitoring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring<br>9. Air Quality Monitoring | What is the main focus of the tool (e.g. temperature, ice fluctuation, sea level rise, snowpack, precipitation, forest planning, permafrost, etc.) | Brief 2-3 sentence description of the purpose of the tool. |
| 9. Air Quality Monitoring | | | | | | | |
| | **Air Pollution in Alaska: Real-time Air Quality Index Visual Map** | https://aqicn.org/map/alaska/ | The World Air Quality Project | Web based map | Air Quality Monitoring | Air Quality Monitoring | Real-time Air Quality Index Visual Map |
| | **The Division of Air Quality, Air Monitoring & Quality Assurance Program** | https://dec.alaska.gov/air/air-monitoring/ | Alaska Department of Environmental Conservation | Website | Air Quality Monitoring | AK Current air quality; air quality monitoring; concerns, projects | Operating ambient air quality monitoring networks; Assessing ambient air quality for ambient air toxics level.<br>Providing technical assistance in developing monitoring plans for air monitoring projects.<br>Issuing Air Advisories to inform the public of hazardous air conditions. |
| | **Alaska Air Quality Index (AQI)** | https://dec.alaska.gov/Applications/Air/airtoolsweb/Aq/ | Alaska Department of Environmental Conservation | Website | Air Quality Monitoring | Downloadable regional reports | Air quality reports |
| 10. Permafrost | | | | | | | |
| | **4th National Climate Assessment, Chapter 26: Alaska** | https://nca2018.globalchange.gov/chapter/26/ | U.S. Global Change Research Program | Web report | Identify applicable Scientific Study Areas: Permafrost, Ice Travel Monitoring<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. IWater Quality Monitoringring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring | Climate Impacts to Alaska | The Alaska regional chapter assess current and future risks posed by climate change and what can be done to minimize risk. Challenges, opportunities, and success stories for managing risk are illustrated through case studies. |
| | **Community Based Permafrost and Climate Monitoring in Rural Alaska** | https://permafrost.gi.alaska.edu/project/community-based-permafrost-and-climate-monitoring-rural-alaska-nsf-1503900 | University of Alaska Fairbanks (UAF) | Research Project | Permafrost | Permafrost | The overarching goal of this project is to help the tribal communities of Upper Kuskokwim region take the lead in assessing and responding to the environmental changes that are coming with warming climate and thawing permafrost. Alaska's land, water, plants, wildlife, and seasons are undergoing a great upheaval, and its people, especially the tribal communities living in remote villages are directly and severely impacted by these changes. The project will help build the tribal capacity to monitor changes in local climate and permafrost by providing the Tribes the scientific knowledge and skills necessary to acquire, analyze, and interpret scientific data through training and education. The project will establish local climate and permafrost observation system and map land cover and permafrost in the Upper Kuskokwim region. It will also develop a geo-hazard map for the region to facilitate safe subsistence and recreational practices and land use. |

| General Information (continued) | Flowchart Components (Conditionally Formatted) - Organizational Filter | | | | | Found on Toolkit |
|---|---|---|---|---|---|---|
| **Main Tool Outputs** | **Data (Complexity)<br>(Low, Medium, High)** | **Geographic Area (G1, G2, G3, G4)** | **[Time frame covered]<br>Published Date<br>(P1, P2, P3, P4, P5)** | **Required Time to Review<br>(RT1, RT 2, RT3, RT4)** | **Bandwidth<br>(B1, B2, B3, B4)** | **U.S. Climate Resilience Toolkit** |
| What are the final products? Map, graph, narrative, shapefile, etc.? (For example, a map might be the primary output, however, the tool may also allow the user to do comparisons, scenarios or generate reports.) | **Low** - Specific to one Scientific Study Area & low complexity<br>**Medium** - Relevant to more than one Study Area & moderate complexity<br>**High** - Need high level of knowledge to interpret information. | **1.** Specific to one of Alaska's 5 Geographic Regions (Far North, Interior, Southwest, Southcentral, Southeast).<br>**2.** Alaska Statewide<br>**3.** National/ International<br>**4.** National/ Local Specific Site. | **1.** Real-time Data<br>**2.** 2011 - 2020<br>**3.** 2000-2010<br>**4.** 1990-2000<br>**5.** <1990 | **1.** 0-30 mins. **2.** 30-60 mir | **1.** Text /Graph (0-5 MB)<br>**2.** Text & Video (5 - 10 MB)<br>**3.** Text & Video, Map (10 -20 MB)<br>**4.** Graphical User Interface (GUI)<br>(Consideration:Delete GUI option; more the norm, than not.) | Is tool found on U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) or not? If yes, insert the url. |
| | | | | | | |
| Map, tables | Low | G2, G4 | P1 | RT1 | B1 | |
| Reports, maps, data | Low | G2 | P1 | RT2 | B1 | |
| Reports, data | Low | G2 | P1 | RT2 | B1 | |
| | | | | | | |
| Report | Medium | G2 | P2 | RT2 | B1 | |
| Poster, Survey, Powerpoint presentations | Low | G1 | P2 | RT1 | B1 | |

| Description | General Information | | | | | | |
|---|---|---|---|---|---|---|---|
| Column Headers | Tool Title / Name of Tool | Link | Organization/Sponsor | Tool Form | All Scientific Study Area(s) | Tool Theme | Description |
| Definition | Enter the tool title. | The URL or link where the tool can be accessed. | The organization and/or sponsor of the tool. | In what form is the tool? (e.g. Web based, spreadsheet, handbook, other). | Identify applicable Scientific Study Areas:<br>1. Coastal Erosion Monitoring<br>2. Flood Preparation Monitoring<br>3. Infrastructure Monitoring<br>4. Water Quality Monitoring<br>5. Cultural & Historical Site Identification & Monitoring<br>6. Extractable Resource Identification (Mapping) & Monitoring<br>7. Wildlife Surveys<br>8. Plant Community Monitoring<br>9. Air Quality Monitoring | What is the main focus of the tool (e.g. temperature, ice fluctuation, sea level rise, snowpack, precipitation, forest planning, permafrost, etc.) | Brief 2-3 sentence description of the purpose of the tool. |
| 11. Collection of Tools | | | | | | | |
| | Scenario Network for Alaska & Arctic Planning (SNAP) | https://www.snap.uaf.edu/ | University of Alaska Fairbanks (UAF) | Web based | All study areas | Available tools include: Community Charts, used to explore temperature and precipitation histories and projections for thousands of communities across Alaska and Canada.<br>Daily Precipitation helps users analyze historical and projected daily precipitation amounts for communities across Alaska.<br>Extreme Weather explores CMIP5 quantile-mapped daily data to analyze the frequency of extreme daily temperature and wind events from 1958 and projected through 2100.<br>Historical Sea Ice Atlas permits users to view historical sea ice data collected between 1850 and the present on an interactive map depicting the seas off northern Alaska.<br>Modeled Sea Ice Coverage allows users to explore and visualize various models of historical and projected arctic sea ice extent and concentration through 2099.<br>Regional Climate Projections uses an interactive map for browsing and comparing climate scenarios created from SNAP data.<br>Sea Ice and Wind lets users examine projected interactions between monthly sea ice concentrations and extreme wind events. | Users in Alaska and Arctic regions near the northern polar extremes can access multiple tools that support climate science and data exploration, allowing for a local focus within the broader context of climate change; temp, ice, wind, precip, etc. |
| | Climate Reanalyzer | https://climatereanalyzer.org/ | University of Maine | Web based | | Platform for visualizing climate and weather datasets | Access climate information using interfaces for reanalysis and historical station data; reviews weather forecasts, climate models and data. |
| | ADAPTAlaska | https://adaptalaska.org/ | Multipartners: Aleutian and Bering Sea Islands LLC, Western AK LLC, APIA, NOAA. ACCAP, Sea Grant, North Pacific LCC, SEATOR, Sitka Tribe of AK, and Tlingit and Haida Indian Tribes of Alaska (Housed by UAF.) | Web based | Touch on all study area, excepting 6.Extractable Resource Identification (Mapping) and Monitoring. | Website that provides resources primarily for Alaska communities to build resilience to climate change. | Provides climate data up to 2019, tools for developing a climate adaptation plan, case studies and other resources. for communities and educators. Links to other key resources and tools. |
| | The US Climate Tool Kit - Arctic/Alaska section | https://toolkit.climate.gov/regions/alaska-and-arctic | NOAA | Case studies, tools, reports on web | All scientific study areas | All aspects of climate cjmage | The website has many tools available to help you manage your climate-related risks and opportunities, and to help guide you in building resilience to extreme events. |
| | Arctic Landscape Conservation Cooperative | http://arcticlcc.org/ | Arctic Landscape Conservation Cooperative (LCC) | Multiple forms | All study areas | Changes in permafrost, vegetation, hydrology and climate | The Arctic Landscape Conservation Cooperative (LCC) conducts applied science and develops tools to support conservation and responsible resource development in the Arctic. Our research addresses understanding and projecting changes in permafrost, vegetation, hydrology and climate to inform habitat conservation and sustainable infrastructure planning. The geographic scope ranges across North America from Alaska to Labrador. |
| | USGS Alaska Science Center | https://www.usgs.gov/centers/asc/ | USGS | Web based resarach articles, publictions, tools | All study areas | Research about ecosystems, plants, animals, climate, energy and mineral assessments, environmental health, natural hazards, and water resources. | The USGS conducts objective scientific research about ecosystems, plants, animals, climate, energy and mineral assessments, environmental health, natural hazards, and water resources.Water resource conditions https://www.usgs.gov/centers/water-dashboard/surface?state=ak. |
| | Monthly (and longer) temperature and precipitation for western Alaska since 1925 (NOAA/NCEI) | https://www.ncdc.noaa.gov/cag/divisional/mapping | NOAA | | Applies to any/all study areas | Temperature/precipitation | This is an easy to use mapping tool where user can ask for specific state, time frame, data on temperature, precipitation, time scale, and a map will be generated. This would be useful to see changes in both over time and how that has impacted warming seas, river erosion, flooding, wildlife and plant communities. Certain time frames do not generate data. |
| | Alaska Climate Adaptation Science Center | https://casc.alaska.edu/about | University of Alaska Fairbanks/USGS | Models, assessments | All study areas | Climate Adaptation | The Alaska Climate Adaptation Science Center (AK CASC) is one of 8 regional Climate Adaptation Science Centers that provide managers with the tools and information they need to develop and execute management strategies that address the impacts of climate change on natural and cultural resources. Our program partners provide expertise in climate science, ecology, environmental impacts assessment, modeling, cultural impacts and advanced information technology. |
| | Local Environmental Observer (LEO) Network | http://www.leonetwork.org/en/#lat=61.74722&lng=-150.0375&zoom=7 | Alaska Native Tribal Health Consortium (ANTHC) | Web based tool | All study areas | Climate Impacts | Tool to help the tribal health system and local observers to share information about climate and other drivers of environmental change.LEO is a network of local observers and topic experts who share knowledge about unusual animal, environment, and weather events. With LEO, you can connect with others in your community, share observations, raise awareness, and find answers about significant environmental events. You can also engage with topic experts in many different organizations and become part of a broader observer community. |
| | Alaska Drought | https://www.drought.gov/drought/states/alaska | National Drought Mitigation Center | Website | All study areas | Drought | Multiple tools to track drought patterns |
| | Arctic Science Portal | https://www.arctic.gov/portal/land.html | United States Arctic Research Commission | Website | All study areas | All aspects of climate | To facilitate access to the broad array of data available on the Arctic, this portal can be thought of as a library of links (URLs) to websites where Arctic data are made publicly available in the main categories of Society, Environment, Economics, Reference, and Organizations. |

| General Information (continued) | Flowchart Components (Conditionally Formatted) - Organizational Filter | | | | | Found on Toolkit |
|---|---|---|---|---|---|---|
| **Main Tool Outputs** | **Data (Complexity) (Low, Medium, High)** | **Geographic Area (G1, G2, G3, G4)** | **[Time frame covered] Published Date (P1, P2, P3, P4, P5)** | **Required Time to Review (RT1, RT 2, RT3, RT4)** | **Bandwidth (B1, B2, B3, B4)** | **U.S. Climate Resilience Toolkit** |
| What are the final products? Map, graph, narrative, shapefile, etc.? (For example, a map might be the primary output, however, the tool may also allow the user to do comparisons, scenarios or generate reports.) | **Low** - Specific to one Scientific Study Area & low complexity<br>**Medium** - Relevant to more than one Study Area & moderate complexity<br>**High** - Need high level of knowledge to interpret information. | **1.** Specific to one of Alaska's 5 Geographic Regions (Far North, Interior, Southwest, Southcentral, Southeast).<br>**2.** Alaska Statewide<br>**3.** National/ International<br>**4.** National/ Local Specific Site. | **1.** Real-time Data<br>**2.** 2011 - 2020<br>**3.** 2000-2010<br>**4.** 1990-2000<br>**5.** <1990 | **1.** 0-30 mins. **2.** 30-60 mi | **1.** Text /Graph (0-5 MB)<br>**2.** Text & Video (5 - 10 MB)<br>**3.** Text & Video, Map (10 -20 MB)<br>**4.** Graphical User Interface (GUI) (Consideration:Delete GUI option; more the norm, than not.) | Is tool found on U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) or not? If yes, insert the url. |
| SNAP datasets are available for download so that researchers and community members can use them in their own research and in community climate analyses. Data and tools are available in a range of formats, allowing for more intensive use by tech-savvy groups and individuals, but are also accessible to the general public. | Medium | G2 | P1, P2, P3, P4, P5 | RT3 | B3 | https://toolkit.climate.gov/tool/scenarios-network-alaska-arctic-planning-snap-tools |
| Maps, timeseries, and correlation analyses can be plotted for gridded models. Station data and model timeseries can be exported in CSV format for use in spreadsheet software. | Medium | G3 | P1 - P5 | RT3 | B2 - B3 | https://www.climate.gov/teaching/resources/climate-reanalyzer |
| Posters, climate adaptation plans, reports, maps, data | Medium | G2 | P2, P3 | RT4 | B3 | https://toolkit.climate.gov/tool/small-community-emergency-response-plan-scerp (Listed Partner on this site.) |
| Depends on the tool chosen | Medium | G2, G3 | P1 - P5 | RT4 | B2 | |
| Multiple | Medium | G1, G2, G3 | P1 (Dependent location and data sought.) | RT3 | B1 | |
| Multiple | Medium | G1, G2, G3 | P1, P2, P3 | RT3 | B3 | |
| Maps for download | Low | G4 | P2, P3, P4, P5 | RT1 | B1 | https://toolkit.climate.gov/tool/climate-glance |
| Models, reports | Medium | G2 | P1 (Dependent location and data sought.) | RT1 | B1 | |
| Map, network | Medium | G2 | P2 | RT1 | B3 | |
| Downloadable data, reports, webinars, map | medium | G2, G4 | P2, P1 | RT1 | B3 | |
| Links to multiple resources | medium | G1 (Far North/Artic) | P1 - P5 (Dependent on data sought.) | RT1 | B1 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **AK Ocean Observing System** | https://aoos.org/; https://portal.aoos.org/#map | Alaska Ocean Observing System (AOOS) part of Integrated Ocean Observing System (IOOS). (Also see http://aoos.org/wp-content/uploads/2011/07/AOOS-101-briefing-PWSRCAC-012315.pdf.) | Web | Coastal Erosion Monitoring; Flood Preparation Monitoring; Infrastructure Monitoring; Wildlife Surveys; Plant Community Monitoring; Water Quality Monitoring; Air Quality Monitoring | Biological, chemical and physical characteristics of Alaska and its surrounding waters. | This portal contains scientific and management information including real-time sensor feeds, operational oceanographic and atmospheric models, satellite observations and GIS data sets that describe the biological, chemical and physical characteristics of Alaska and its surrounding waters. |
| | **US TEK Literature** | https://www.nps.gov/subjects/tek/united-states.htm | National Park Service | Website | Applies to any/all study areas | TEK | NPS website with many resources. Map of U.S. Eco-regions, based on the Cooperative Ecosystem Studies Units CESU. For the United States, information on TEK has been organized by seven major areas and sub-divided into smaller areas. Issues, resources, funding for, policies, etc on this site. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Data comparison and charting functions; featured data views; advanced charting features, including climatologies and anomalies; station and source level metadata pages; and shareable custom data views. | | medium | G2 | P1-5 | RT3 - RT4 | B3 | | |
| Variety of outputs | | Medium | G2, G4 | P1, P2, P3 | RT2 - RT3 | B1 | | US Climate Tool Kit Related links: https://toolkit.climate.gov/tool/tribal-resilience-resource-guide https://toolkit.climate.gov/regions/alaska-and-arctic/arctic-peoples-and-ecosystems https://toolkit.climate.gov/tool/atlas-community-based-monitoring-and-traditional-knowledge-changing-arctic https://toolkit.climate.gov/tool/guidelines-considering-traditional-knowledges-climate-change-initiatives https://toolkit.climate.gov/tool/seven-generations%E2%80%94community-based-environmental-planning |

# APPENDIX C: INTEGRATION/APPLICATION OF DATA INTO PLANNING MATRIX

The UAS feasibility study reviewed selected plans and reports at four scales (local, regional, state, and federal) to identify potential integration points for drone data and how it may apply to planning and decision making processes. A sampling of plans and reports were reviewed. Their relevance for integration and application is outlined in the following Integration/Adaptation of Data into Planning Matrix.

**UNALAKLEET FEASIBILITY PROJECT: INTEGRATION/APPLICATION OF DATA INTO PLANNING MATRIX**
**(Representative Sample of Potential Applications of Data.)**

| DOCUMENT or RESOURCE TITLE /DATE | PLANNING DOCUMENT/RESOURCE OVERVIEW | | RECOMMENDATIONS FOR DATA INTEGRATION (APPLICATION) | |
|---|---|---|---|---|
| | **Citation/ File Location (URL)** | **Document Description** | **Chapters/Sections &/or Page #s, if known.** | **Additional Comments** |
| **Unalakleet (Tribal, City & Native Corporation) Documents** | | | | |
| **City of Unalakleet Hazard Mitigation Plan, December 2015** | City of Unalakleet Hazard Mitigation Plan. Prepared by The City of Unalakleet HMP Planning Team, Hazard Mitigation Planning Team. December 2015. No online link available. | The City of Unalakleet's HMP describes the community, the hazard mitigation planning process, and a detailed analysis of natural hazards, the assets and vulnerabilities of the community, and the hazard mitigation strategies to be implemented that help protect the people, infrastructure, and natural systems of the community. | | Applications of UAS information gathering and analysis are relevant to the process of hazard mitigation planning, specifically in the chapters on community description, the planning process, hazard analysis, vulnerability assessment, mitigation strategy, and implementation of the mitigation action plan. See review notes for additional details. |
| **City of Unalakleet, Alaska: Local Hazards Mitigation Plan (HMP)/ Rv. June 30, 2008** | City of Unalakleet, Alaska /Local Hazards Mitigation Plan. Prepared by: City of Unalakleet WHPacific, Inc. of Alaska Bechtol Planning and Development. Date of Plan: April 22, 2008; revised June 30, 2008. Available online at: https://web.law.columbia.edu/sites/default/files/microsites/climate-change/files/Arctic-Resources/Community-Adaptation-Plans/Unalakleet_LHMP.pdf | This document has been updated with the *City of Unalakleet Hazard Mitigation Plan, December 2015.* | | Included since *City of Unalakleet Hazard Mitigation Plan, December 2015* is unavailable online. |
| **Unalakleet Local Economic Development Plan (LEDP) 2014 - 2019** | Unalakleet Local Economic Development Plan 2014-2019. Prepared for The Community of Unalakleet and The Bering Strait Development Council. Facilitated By: Simon Ellanna Strickling, Planning and Development Specialist Community Planning and Development, Kawerak, Inc. Available online at: https://kawerak.org/wp-content/uploads/2018/02/Unalakleet.pdf. | The Unalakleet Local Economic Development Plan (LEDP) is a joint effort undertaken, generally every 5 years, by the Native Village of Unalakleet, City of Unalakleet, and Unalakleet Native Corporation, with assistance from the Kawerak Community Planning and Development Program staff, in order to determine the community's values, goals, objectives and strategies to guide future growth and economic development. | UAS-collected data is relevant to Chapters 3.4 Community Infrastructure, 5.0 Environmental Scan, and 9.0 Development Priorities and Implementation. | Localized UAS data collection and analysis are relevant to the a local economic development planning program for not only establishing a baseline of relevant data but ongoing monitoring. Furthermore, development of a localized UAS program can be an economic strategy of its own, by potentially providing a critical data collection service to other neighboring communities and regional, state and federal agencies. See review notes for additional details. |
| **Small Community Emergency Response Plans (SCERP) (Unalakleet, like many other Alaska small communities, has developed its own SCERP, last updated July 2019.)** | Alaska Division of Homeland Security & Emergency Management. (2021). Small Community Emergency Response Plan. Retrieved from https://ready.alaska.gov/Plans/SCERP. | The State of Alaska developed the Small Community Emergency Response Plan (SCERP) as an approach to emergency management for small communities with a population of 2,000 or less. The SCERP, put together by a local Community Planning Team, is a customized flip book with essential, community-specific information for responding to a disaster. Through such planning (and disaster response exercises), it provides those on the ground a course of action to immediately respond to a local disaster and coordinate with outside emergency response agencies such as the Alaska Division of Homeland Security & Emergency Management and the State Emergency Operations Center (SEOC). | Specific sections of the SCERP where a sUAS program could fit in are:<br>- The First 4 Hours<br>- The First 12 Hours<br>- The First 24 Hours<br>- Through 48 Hours<br>- Beyond 72 Hours<br>- Sheltering and Evacuation<br>- Evacuation<br>- Damage Assessment and Resource Requests | |
| **Regional Documents** | | | | |
| **Bering Strait: Marine Life and Subsistence Use Data Synthesis (2014)** | Bering Strait: Marine Life and Subsistence Use Data Synthesis (2014) Oceana, Inc. and Kawreak, Inc. https://oceana.org/publications/reports/the-bering-strait-marine-life-and-subsistence-data-synthesis#:~:text=Oceana%20and%20Kawerak%2C%20Inc.,benthic%20habitat%20and%20sea%20ice. | This book provides an information , data, and mapping synthesis review of the regional subsistence resources, marine species, and marine ecosystems for the Bering Strait region. "The goal of this data synthesis is to assist policymakers, including tribal governments in the region, in making informed decisions." The synthesis represents information from both traditional ecological knowledge and Western science. | See Map 3.13 showing an example of fishing subsistence data gap areas in the Norton Bay region | The report's focus on TEK and Western science data for location, abundance, and health of subsistence resources, marine species, and marine ecosystems offers prime opportunities for interpreting UAS findings and integrating UAS data into decision making processes. The report states that, "The goal of this data synthesis is to assist policymakers, including tribal governments in the region, in making informed decisions." UAS data can help address data gaps identified in the report and provide a mechanism to improve local tribal engagement. "Many important management and policy decisions affecting the Bering Strait region will be made in the next few years, and decision-makers must engage the tribes of the region.2 Tribes have a legal right to government-to-government consultation,3 and tribal members have traditional ecological knowledge that is relevant for decision-making.4,5" |
| **State Documents** | | | | |
| **2015 Alaska Wildlife Action Plan** | Alaska Department of Fish and Game. 2015. Alaska Wildlife Action Plan. Juneau. http://www.adfg.alaska.gov/static/species/wildlife_action_plan/2015_alaska_wildlife_action_plan.pdf | An Alaska statewide plan for managing fish and wildlife species and their habitats to help prevent listings under the Endangered Species Act. | | |
| **Federal Documents** | | | | |
| **Fourth National Climate Assessment: Chapter 26 Alaska** | Markon, C., S. Gray, M. Berman, L. Eerkes-Medrano, T. Hennessy, H. Huntington, J. Littell, M. McCammon, R. Thoman, and S. Trainor, 2018: Alaska. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. May cock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1185–1241. doi: 10.7930/NCA4.2018.CH26 https://nca2018.globalchange.gov/chapter/alaska; and https://nca2018.globalchange.gov/downloads/NCA4_Ch26_Alaska_Full.pdf | Summary of climate change impacts, risks, and potential adaptation actions for state of Alaska, with a focus on marine systems, terrestrial processes, human health, indigenous peoples, economic costs, and proactive adaptation. | | |
| | | | | |

**UNALAKLEET FEASIBILITY PROJECT: INTEGRATION/APPLICATION OF DATA INTO PLANNING MATRIX**
**(Representative Sample of Potential Applications of Data.)**

Questions to Answer: What data is relevant to which documents? How can the data be integrated into each type of report? Where can the data be used to help local (regional) decision makers?

| DOCUMENT or RESOURCE TITLE /DATE | APPLICABLE TO THE SCIENTIFIC STUDY AREA (Please check all that apply.) | | | | | | | | | | | | | | | | | | Total Relevancy Value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coastal Erosion | Relevancy Low : 1/ Med: 2/ High: 3 | Flood Preparation | Relevancy Low : 1/ Med: 2/ High: 3 | Infrastructure | Relevancy Low : 1/ Med: 2/ High: 3 | Water Quality | Relevancy Low : 1/ Med: 2/ High: 3 | Air Quality | Relevancy Low : 1/ Med: 2/ High: 3 | Wildlife | Relevancy Low : 1/ Med: 2/ High: 3 | Plant Community | Relevancy Low : 1/ Med: 2/ High: 3 | Cultural & Historical | Relevancy Low : 1/ Med: 2/ High: 3 | Extractable Resources | Relevancy Low : 1/ Med: 2/ High: 3 | |
| **Unalakleet (Tribal, City & Native Corporation) Documents** | | | | | | | | | | | | | | | | | | | |
| City of Unalakleet Hazard Mitigation Plan, December 2015 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 2 | ☑ | 2 | ☑ | 2 | ☑ | 2 | ☑ | 3 | ☑ | 1 | 21 |
| City of Unalakleet, Alaska: Local Hazards Mitigation Plan (HMP)/ Rv. June 30, 2008 | ☐ | | ☐ | | ☐ | | ☐ | | ☐ | | ☐ | | ☐ | | ☐ | | ☐ | | N/A |
| Unalakleet Local Economic Development Plan (LEDP) 2014 - 2019 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 1 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | 25 |
| Small Community Emergency Response Plans (SCERP) (Unalakleet, like many other Alaska small communities, has developed its own SCERP, last updated July 2019.) | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 2 | ☑ | 2 | ☑ | 2 | ☑ | 1 | ☑ | 2 | 21 |
| **Regional Documents** | | | | | | | | | | | | | | | | | | | |
| Bering Strait: Marine Life and Subsistence Use Data Synthesis (2014) | ☑ | 3 | ☑ | 2 | ☑ | 2 | ☑ | 3 | ☑ | 2 | ☑ | 3 | ☑ | 1 | ☑ | 3 | ☑ | 3 | 22 |
| **State Documents** | | | | | | | | | | | | | | | | | | | |
| 2015 Alaska Wildlife Action Plan | ☑ | 3 | ☑ | 2 | ☑ | 2 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 2 | 24 |
| **Federal Documents** | | | | | | | | | | | | | | | | | | | |
| Fourth National Climate Assessment: Chapter 26 Alaska | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 3 | ☑ | 2 | ☑ | 2 | ☑ | 2 | 24 |
| | Coastal Erosion | 18 | Flood Preparation | 16 | Infrastructure | 16 | Water Quality | 17 | Air Quality | 13 | Wildlife | 16 | Plant Community | 13 | Cultural & Historical | 15 | Extractable Resources | 13 | |
| | Study Area Overall Relevancy | | | | | | | | | | | | | | | | | | |

# APPENDIX D: ENVIRONMENTAL MONITORING WITH UNMANNED AERIAL VEHICLES: COST ESTIMATING & ANALYSIS

By Barbara Cozzens, MEM

## BACKGROUND

In the context of natural and other resource monitoring, unmanned aerial vehicle (UAV) systems are touted as having several advantages: Flexibility, maneuverability, efficiency, high spatial and temporal resolution, low-altitude flight capabilities, and lower costs. While the gains offered by UAVs have been highlighted and in most cases empirically demonstrated in both reports and studies, few details have been shared related to costs.

This study collates and systematically presents the fragmented data on UAV data collection and analysis costs in the context of the nine study areas. Analogous cost estimating is then used to derive cost estimates for a range of applications. Given the scarcity of historical cost data and analyses, the number of study areas, and the variety of environmental contexts, scales, constraints, and variables that could be assessed with UAV systems, it's impractical to provide these estimates with any measure of confidence. However, these estimates can serve as guideposts to help inform and strengthen decisions.

## METHODS

Study area-specific keywords were selected and used to search[1] Google Scholar inventories for scientific papers detailing the costs of monitoring with UAVs and/or traditional methods. Grey literature searches and snowballing were also heavily utilized. More than 150 studies contributed some combination of qualitative and quantitative costs, accuracy assessments, and methodological guidance.

Cost estimates were then modeled using analogous estimating – a technique similar to an economic "value transfer" approach – where historical data for a similar activity or project are used to estimate the cost of a planned project. Expenses derived from using drones are difficult to quantify and depend on a confluence of factors. In many cases, applications described in studies relied on the acquisition of sophisticated onboard instruments, devices, and sensors, or advanced communications systems. To ensure like-with-like comparisons, many of these factors and details needed to be teased out from the already deficient cost data. In many cases, this required direct communication with the studies' authors and UAV manufacturers.

Values were then expressed in the same currency, standardized to the same scale (where possible), and expressed in real dollars using the consumer price index and 2020 as the base year. Costs determined from international sources were converted to U.S. dollars at the conversion rates for the year of study publication, before adjusting for inflation.

Based on the type, number, and veracity of values, a variety of analogous estimating techniques were utilized:

- If costs could be scaled to a single parameter – for example, $ per hectare – an algorithm was developed to calculate a **parametric cost estimate**.

[1] Searches conducted between June through December 2020

- **Single point estimates** were used where only a single value was known. Single Point estimates are typically inaccurate and therefore risky.
- If two or three values were known, estimates were derived through a **statistical mean** or **triangular distribution**.
- Where there were notable irregularities in historical values, a weighted average was calculated using a **PERT formula based on beta distribution**.

## Assumptions

- UAV/drone technology is changing rapidly. When fielded, these new capabilities may change the cost or accuracy comparisons dramatically.
- All values have been adjusted to a constant dollar and rescaled, or indexed, to a per-unit cost. However, **not all methodologies are scale neutral**. For example, manned aerial surveys have a minimum fixed or upfront barrier before costs scale variably, either spatially or temporally. Similarly, satellite-based methods require a minimum buy of 50 $km^2$. Where such minimum limitations are known, these were incorporated into the scalar cost.
- Unless otherwise specified, values represent aggregate total costs, including equipment, acquisition, georeferencing and orthorectifying, image processing, and staff costs. Given the variability in the aggregation and reporting of cost data in the studies, it would be impossible to compare specific costs directly. For example, commercially-acquired satellite images include operational and development costs into the unit price.
- Drawing direct comparisons between methodologies is inherently challenging. Which solution is most cost-effective depends on the management or research requirements. In this case, methodologies vary not only between study areas but within study areas based on targets or goals. Where possible, cost data is presented granularly, but this only helps to a degree. As such, the following costs should be used as guideposts rather than explicit estimates.
- Transfer errors are routinely assessed in value transfer studies. These errors can be associated with dissimilarities between the study site and the policy site, the method used to transfer values, lack of consistency in reporting scales, errors in rescaling, and researcher reporting or calculating errors (amortization, underreporting). While every effort has been made to minimize transfer errors – including but not limited to direct contact with study site researchers – such errors should be anticipated.

# SCIENTIFIC STUDY AREAS

Cost analyses and estimates for each of the nine study areas follows. Though the study areas are treated independently, they should not be considered in complete isolation from one another. For accuracy, the cost estimates are based on historical data – costs and values – from studies and reports within the same study area. It is reasonable, however, to approach cost data for similar applications outside the study area. A summary of the overlaps of cost data and monitoring approaches follows in the table below.

Likewise, decisions concerning the application of UAV should therefore assume some measure of economies of scale: A monitoring mission for one purpose can also be used to generate data for another purpose, thus spreading costs over a larger number of objectives.

| | Scientific Study Areas | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Mode / Method** | **Vegetation** | **Wildlife** | **Coastal Erosion** | **Flooding** | **Infrastructure** | **Cultural & Archaeological Heritage** | **Extractive Industries** | **Air Quality** | **Water Quality** |
| **Page** | **3** | **5** | **8** | **9** | **10** | **11** | **12** | **12** | **14** |
| **On Ground** | | | | | | | | | |
| Trained Technician | ● | | | | ● | ● | | | ● |
| Pellet-Count Surveys | | ● | | | | | | | |
| Hunter Observations | | ● | | | | | | | |
| Weir | | ● | | | | | | | |
| Tower Count | | ● | | | | | | | |
| **Satellite** | | | | | | | | | |
| Satellite | ● | | | ● | | | | | |
| **Fixed Wing Aircraft** | | | | | | | | | |
| Ocular | | ● | | | ● | | | | |
| Multi-spectral sensors: NDVI | ● | | | | | | | | |
| FUR | | ● | | | | | | | |
| SfM | | | | | | | ● | | |
| DEM | | | | ● | | | | | |
| **Other** | | | | | | | | | |
| Terrestrial Laser Scanner | | | ● | | ● | | | | |
| Kite | | | ● | | ● | | | | |
| Pole | | | ● | | | | | | |
| Portable Particle Counter | | | | | | | | ● | |
| Air Sampling Station | | | | | | | | ● | |
| **UAV** | | | | | | | | | |
| Photogrammetry | | | | ● | ● | ● | | | |
| SfM | ● | ● | ● | | | | ● | | |
| Multi-spectral sensors: NDVI | ● | | | | | | | | |
| Thermal Imaging | | ● | | | | | | | |
| GNSS | | | | | | ● | | | |
| Spectroradiometer | | | | | | | | | ● |

# Vegetation Monitoring

Long-term monitoring of plant communities provides invaluable information for assessing the current ecological conditions of an area and measuring responses to short-term disturbances and long-term changes. Data trends, in turn, help guide management decisions.

Methods to monitor vegetation depend on specific management or research goals. Traditional methods rely on hands-on, ground-based surveys, which are expensive, labor-intensive, and impractical for anything but small spatial scales. These spatial constraints have been largely resolved by remote sensing, which utilizes primarily aerial sensors to detect plant species or plant communities by their unique properties – distribution, structure, color, and texture.

Remote sensors can acquire data passively or actively. Passive sensors measure variations in light reflectance and classify or identify plants or plant communities based on their spectral signature using indices such as the Normalized Difference Vegetation Index (NDVI). Active sensors, such as Light Detection and Ranging (LiDAR), send many pulses per second and measure the signals that bounce back to determine different properties.

In the last 20 years UAVs have been successfully utilized to detect, assess, and predict changes to plant communities to support ecological research and conservation objectives. Drones are commonly used in forest monitoring and have been employed to detect illegal logging (Paneque-Gálvez et al., 2017) and deforestation (Messinger et al., 2016); estimate fuel loads; monitor and detect forest fires and the resulting damage and recovery (Yuan et al., 2015); and detect fallen trees and damage to vegetation following extreme weather events (Inoue et al., 2014). Increasingly, UAVs are also being used to map the distributions of individual plant species and vegetation types at a fine spatial scale; monitor health conditions and ecological succession dynamics of plant communities; detect fungal and insect pathogen infections and damage (Michez et al., 2016); detect, map and monitor invasive plant species (Müllerová et al., 2017); and to detect harmful algal blooms in water bodies (Shang et al., 2017).

On the whole, there is a consensus that UAVs are the more cost-effective option for monitoring vegetation at sites between 10 and 20 hectares (ha) when compared to manned aircraft and satellite data. While hundreds of studies detail UAV use for monitoring plant communities, only a small fraction provide concrete cost data. And to date, only a handful of cost-benefit analyses have been published comparing UAVs to traditional monitoring methods. Two of the five sources utilized to derive the parametric cost estimates that follow included simple cost-benefit analyses. A summary of these sources follows:

- Ref. 1: Navarro et al. (2017) compared using UAV Structure from Motion (SfM) to on-the-ground measurements for monitoring above-ground biomass of Australian mangrove forests. After 100 days of surveys, the UAV-based approach covered an area 250 times larger than on-ground surveys while maintaining data accuracy. The authors performed a simple cost-benefit analysis of the two methodologies, which revealed that staff salaries for data acquisition and processing of on-ground measurements were almost double those of the UAV-SfM approach. UAV-SfM methods were found to save almost AU$ 50,000 per ha when compared to on-ground measurements and become cost-effective (based on total costs) after just 15 days of surveys.
- Ref. 2: Matese et al. (2015) compared NDVI surveys using UAV, aircraft, and satellite to assess vegetative spatial variability at Italian vineyards. The team's evaluation included both operational and economic factors. The platforms produced comparable results in vineyards characterized by coarse vegetation gradients and large vegetation clusters. However, in more heterogeneous vineyards, low-resolution images failed to represent intra-vineyard variability, critically important for precision viticulture. In this study, UAV was the most cost-effective approach for small areas, under 5 ha, due to the low cost of data acquisition. On larger plots, aircraft and then satellite had lower costs.

- Ref 3: In a survey of the use of UAV for environmental monitoring, Manfred et al. (2018) reported that a newly tasked high-resolution natural color image (50 cm/pixel) from a satellite (e.g., GeoEye-1) can cost up to $3,000 USD.
- Ref 4: Baena et al. (2017) cited a cost of $33 per km for high-resolution satellite imagery.
- Ref 5: Sankey et al. (2019) generalize on-ground field survey costs at approximately $180/plot for every 2–3 ha, or $90 per ha for a single sampling period. It's unclear if this value includes all associated costs (ex. vehicle, gas, etc.).

**Analogous Costs and Parametric Cost Estimates for Monitoring Vegetation: Total Costs Per Hectare (US$)**

| Ref | On Ground | Satellite (per 1 ha to 50 ha) | Manned Aircraft | UAV |
|---|---|---|---|---|
| 1 | $40,087 | | | $102 |
| 2 | | $3,642 | $673 | $605[2] |
| 3 | | $3,017 | | |
| 4 | | $3,503 | | |
| 5 | $932 | | | |
| Statistical Mean | **$20,060** | **$3,387** | **$673** | |
| Weighted Cost Estimate | **$32,256** | | | **$203** |

Empirical | Reported | Most Likely | Ambiguous Value | High Certainty (Triangular Distribution)

# Wildlife

Biologists monitor wildlife populations for research, management, and decision-making purposes. A wide variety of direct and indirect methods are used. Indirect methods estimate population or abundance using indices such as fecal pellets, spawning nests or REDDs, or burrow counts. Direct methods look to observe the animals directly and utilize methods such as hunter-harvest data or observations, aerial surveys, and capture-mark-resight models. The optimal monitoring method for a given study depends entirely on goals and objectives, species characteristics (e.g., size, diurnal vs. nocturnal, color, etc.), spatial scale, and budget.

Sensitive or aggressive species, or those in remote habitats, are difficult to monitor with traditional, ground-based methods. In such cases, UAV makes wildlife monitoring, management, and protection possible and often provides more precise results compared with traditional surveying. For example, Weissensteiner et al. (2015) used an inexpensive UAV to assess the nesting status of a canopy-nesting passerine bird. UAV equipment costs were less than half that of equipping two technicians with climbing gear. More significantly, 85% of the time required for inspection by climbing could be saved. Disturbance to the birds was moderate and lower than what would be caused by climbing or using a camera on a telescopic rod. Additionally, UAV usage avoided tree damage and the potential for additional health and safety costs.

UAVs are commonly used to estimate population abundance and distribution, observe wildlife behavior, map habitat and range, and monitor illegal activities such as poaching and illegal trade of wildlife (Xiang, 2019). Targets are most often large terrestrial mammals, marine mammals, and birds (e.g. snow geese) (Xiang, 2019)

[2] Does not include equipment cost

(Nowak, 2018). It's widely understood that accuracy and variation in animal detection and identification from UAV images depend on the visual permeability of the species' habitat and the species' behavioral traits. For example, elusive and cryptic wildlife are often under-represented in UAV surveys.

Based on presumed wildlife management needs in the region, the scope of this analysis was limited to monitoring methods used to estimate the abundance of large mammals (ex. moose, caribou), birds, and fish, notably salmonids.

While the number of studies describing UAV use for monitoring wildlife has increased dramatically in recent years, only a tiny fraction provides concrete cost data. Fewer still provide cost comparisons, formal or informal. A summary of sources follows:

- Ref. 6: Mansson et al. (2011) tested the relative performance of three methods for monitoring populations of Swedish moose: aerial survey, pellet-group counts, and hunters' observations. They both measured performance and cost. Annual aerial surveys were the most costly method (27,000E) and maintained the population within the desired range 72% of the time. Hunters' observations, less expensive by a factor of 15, maintained the population within a desired range 66% of the time. A combination of annual pellet-group counts and hunters' observations was both most effective and least expensive.
- Ref. 7: Watts et al. (2011) estimated a US$0.21per ha survey cost using a University-developed small UAS. This assumes a typical mission profile in which 240 ha is surveyed per flight and an airframe cost (minus payload) of US$5,000 amortized over a hypothetical operational life of 100 missions. Their estimate did not include the amortized acquisition or personnel costs, which represent the primary expense of UAS deployment; maintenance and operational costs for the UASs are negligible by comparison.
- Ref 8: (2018) The USGS's Upper Midwest Environmental Science Center (UMESC) and the USFWS Migratory Bird Surveys Branch (MBSB) partnered to survey sandhill cranes staging on the Platte River Valley during spring migration. The agencies have traditionally conducted low-level aerial surveys during daylight hours, but the dispersal of the cranes to feed has contributed to variable crane counts. At night the birds concentrate on the river to roost, making them easier to count. The agencies tested using a UAV to survey at night using thermal imaging. At $2,600, the UAV cost just over half of what a government-manned aircraft survey would cost and approximately 15 times cheaper than a contractor-manned aerie aerial survey. The data collected by the drone was reportedly the most accurate ever collected.
- Ref 9: *Salmonid Field Protocols Handbook: Techniques for assessing status and trends in salmon and trout populations* (2008) provides a range of cost estimates for establishing a remote counting tower field site, a picket weir, or a floating weir. In general, there is a positive correlation between project cost and the remoteness of the site. Salary, permits, food, fuel, and transportation costs were not included due to wide variation in cost among potential sites.
- Ref 10: Fisheries and Oceans Canada (2015) reported having budgeted $26,800 to complete aerial survey counts of select Stikine River Chinook Spawning Sites.

- Ref 11: Groves et al. (2016) tested the use of UAVs for counting Chinook salmon redds below the surface waters of two spawning areas along a stretch of the Lower Snake River that flows along the borders of Washington, Oregon, and Idaho. Redd counts taken from those UAS-derived images were more accurate than counts made from a manned helicopter. Counting redds from the helicopter, however, was less expensive and time-consuming.

## WILDLIFE (UNGULATES & BIRDS)

**Analogous Costs and Parametric Cost Estimates for Wildlife Monitoring: Total Costs Per Hectare (US$)**

| | On Ground | | Manned Aircraft | | UAV | |
|---|---|---|---|---|---|---|
| Ref | Pellet-Group Count | Hunter Observation | Ocular | Dual Thermal Infrared (FUR) | Photogrammetry | Thermal Imaging |
| 6 | $0.14 | $0.03 | $0.45 | | | |
| 7 | | | | | $0.25[3] | |
| 8 | | | $0.81 | $6.60 | | $0.50 |
| Single Point Estimate or Statistical Mean | **$0.14** | **$0.03** | **$0.63** | **$6.60** | **$0.38** | |
| Weighted Cost Estimate | | | | | **$0.45** | |

## FISH (SALMONIDS)

**Analogous Costs and Non-Parametric & Parametric Cost Estimates for Fish Monitoring: (US$)**

| Ref | Tower Count | Weir | Manned Aircraft: Ocular (Escapement) | Manned Helicopter REDD Counts | UAV: Photogrammetry |
|---|---|---|---|---|---|
| 9 | $12,643 (OE) to $59,889 (PE) | $87,970 (picket weir) - $137,079 (floating weir) | | | |
| 10 | | | $29,424 | | |
| 11 | | | | $4,300/km$^2$ | $5,496/km$^2$ |
| Single Point Estimate | **$36,266** | **$87,970 (picket) - $137,079 (floating)** | **$29,424** | **$4,300/km$^2$** | **$5,496/km$^2$** |

Empirical   Reported   Most Likely   Ambiguous Value

[3] Airframe and survey costs. Does not include

# Coastal Erosion

Monitoring short-term and long-term changes to coastlines is critically important to understanding coastal evolution and managing coastal environments. Measurements of positional changes in shorelines and foredunes can help quantify rates of change, and provide invaluable information on storm impacts, site characteristics, annual cycles, and resilience to sea-level change.

The selection of the best tool for monitoring detailed coastline evolution largely depends on the size of the study area. For small study areas – several kilometers of longshore – surveys often utilize roving (human or vehicle) real-time kinematic GPS. For larger-scale sites, researchers have utilized airborne laser altimetry, terrestrial and airborne LiDAR, and, more recently, Structure from Motion (SfM) photogrammetry. SfM generates a three-dimensional topographic surface from multiple overlapping photographs. Coastal indicators such as shoreline position and subaerial beach volume can be derived from these models – often a digital elevation model (DEM) – and used to quantify changes between surveys. Accurate, high spatial resolution is required to accurately monitor coastal evolution. And the need for frequent data collections means surveys can be costly and time-consuming, particularly in remote or sensitive areas.

To overcome the limitations of traditional methods, UAVs are now being employed to monitor beach-dune morphological changes and beach morphodynamics (Brunier, 2016); reconstruct beach topography (Mancini, 2013); quickly assess storm impacts; and monitor recovery. UAS surveys allow for more immediate, flexible, and less resource-intensive deployment. When paired with SfM, the imagery and derived topographic data are available at considerably higher resolutions and spatial point densities than other surveying methods, particularly in sandy beach areas (Sturdivant, 2017).

UAVs have reportedly been underutilized for coastal management (Sturdivant, 2017). Inclusion of cost data or cost comparisons in these studies is rare; thus the search for historical cost data was broadened to include all erosion-related studies or reports involving proximal remote sensing to collect topographic data. A summary of sources follows:

- Ref 12: Glendell et al. (2017) compared terrestrial laser scanning (TLS), and both UAV- and ground-based SfM derived topography for quantifying soil volumes lost via erosion. They compared cost-effectiveness and accuracy of both SfM techniques to TLS by recording the amount of time spent in the field on an initial walkover survey, site marking, field surveying, and data post-processing (including data cleaning, georeferencing, DEM elaboration). Computer CPU time for data post-processing was also recorded. Soil loss estimates from UAV and ground-based SfM reconstructions were comparable to those from TLS. Both UAV and GP were of comparable cost with the TLS on a per-site basis; however ground-based SfM was less suitable for surveying larger areas.
- Ref 13: Conlin et al. (2018) quantitatively compared multiple low-cost kite-, pole-, and unmanned aerial vehicle (UAV)–based SfM data collection platforms for measuring beach and dune topography. UAV-based platforms received high performance scores, mainly because "these stable, high-flying platforms provide images with adequate texture to allow accurate three-dimensional topographic reconstruction". Although data from the kite- and pole-based systems were less accurate, the platforms have a lower barrier to entry and fewer environmental limitations (e.g., wind), which increased their overall performance.

- Ref 14: Ruggles et al. (2015) compared UAV-derived point cloud models to TLS at the site of a large landslide in Arizona. Point cloud resolution improved by more than 16% when using multi-rotor UAVs instead of fixed-wing UAVs. They compared both equipment cost and man-collection hours.

**Analogous Costs and Parametric Cost Estimates for Coastal Erosion Monitoring: Costs Per Hectare (US$) Plus Equipment Costs**

| Ref | Ground-Based SfM | UAV SfM | Terrestrial Laser Scanner | Kite | Pole |
|---|---|---|---|---|---|
| 12 | $28,853 +$1014 equip | $332 +$2027 equip. | $395 +$143,865 equip | | |
| 13[4] | | $4 +$1,295 equip | | $8 +172 equip. | $12 +284 equip. |
| 14 | | $67 $4,136[5] | $705 +$108,296 equip | | |
| Single Point or Statistical Mean Cost Estimate | | **$2,486 equip.** | **$550 +126,081 equip.** | **$8 +166 equip.** | **$12 +274 equip.** |
| PERT with Beta Distribution Cost Estimate | | **$233 per ha** | | | |

Empirical | Reported | Most Likely | Ambiguous Value

*Time values were scaled to dollars using the U.S. Bureau of Labor Statistics' Occupational Employment and Wages mean hourly wage estimate for surveyors, cartographers and photogrammetrists: $33.55 (https://www.bls.gov/oes/current/oes171021.htm)

# Flooding

Hydrologic and hydraulic data and tools are essential for understanding, forecasting, and mitigating flood hazards. Satellite sensors are currently used to monitor rivers and delineate flood zones; their popularity is due to their wide coverage, spectral resolution, safety, and rapid rate of update (Manfreda et al., 2018). But a lack of detail in satellite-derived topographic datasets can reduce the accuracy of flood models for anything but large rivers and areas of inundation (Annis et al., 2020).

UAVs can monitor river dynamics with a level of detail that is several orders of magnitude greater than satellite. They can also capture flow measurements over smaller river systems and tributaries and in difficult-to-access environments. On the whole, UAVs provide very high resolution and accurate digital elevation models (DEMs) with low surveying cost and time, as compared to DEMs obtained by Light Detection and Ranging (LiDAR), satellite, or ground-based GPS fieldwork.

To date, UAV-derived data has supported rainstorm modeling (Backes et al., 2019), channel reconstruction, flood modeling (Mourato et al., 2017), debris-flow monitoring (Wen et al., 2011), surface-water detection after a flood event, flyover inspection of dykes (Skrzypietz, 2012), and glacier-dammed lake monitoring. For example, Kienholz et al. (2020) utilized UAV to collect vertical aerial images across Alaska's Suicide Basin, an area that has released glacier lake outburst floods (GLOFs) annually since 2011. Resulting DEMs and

[4] Time estimates only include time to collect the photos
[5] Mean of UAV costs

orthomosaics via structure-from-motion (SFM) photogrammetry were used to assess surface mass balance, ice-flow dynamics, and lake evolution on sub-seasonal to multi-annual time scales and discuss their impact on the basin's storage capacity.

Cost data or cost comparisons in hydrologic studies using UAV are remarkably rare. A summary of sources follows:

- Ref. 15: Annis et al. (2020) compared LiDAR DEM, UAV, and a nation-scale high-resolution DEM (TINITALY) for representing floodplain topography for flood simulations. UAV-derived DEM flood simulations performed significantly better than those derived from the TINITALY DEM. UAV-derived DEMs could be an appropriate alternative to the LiDAR DEM for small basin flood mapping. Staff time represents more than 80% of the UAV costs described below. Authors suggest Advances in UAV-derived DEMs, such as Structure from Motion (SfM) techniques, would reduce surveying costs and times while covering inaccessible areas.
- Ref 16: Wolken, one of the investigators on the Alaska outburst flood study (Kienholz et al., 2020), reported that helicopter surveys cost the team $3,500 USD.

**Analogous Costs and Parametric Cost Estimates for Flood Monitoring: Costs Per Hectare (US$)**

| Ref | Manned Aircraft Photogrammetry | Manned Aircraft LiDAR 1 m DEM | UAV DEM | INGV-TINITALY 10 m DEM |
|---|---|---|---|---|
| 15 | | $40 | $500 | Free |
| 16 | $13 | | | |
| Single Point or Statistical Mean Cost Estimate | **$27** | | **$500** | **Free** |

Empirical    Reported

# Infrastructure

Regular inspections of built environments are necessary to assess the current condition of critical infrastructure. The results, in turn, help engineers prioritize maintenance, remediation, and critical repair needs.

Traditionally, inspections are done visually, often using inspection units, mobile scaffolding, boom lifts, and cherry pickers. Thermography, ultraviolet cameras, airborne LiDAR and terrestrial laser scanning are also frequently utilized. The time, resources, and costs associated with these methods have led to an increasing backlog of maintenance activities.

UAVs have the potential to optimize the monitoring of buildings, electrical grids, oil and gas lines, roads, railways, dams, water reservoirs, airports, maritime routes, and bridges. For example, UAV-acquired visible and infrared images have been used to monitor the condition and structural health of bridges, including bridge deterioration, deck delamination, aging of road surfaces, and crack and deformation detection (Ellenberg, 2016). Likewise, UAVs have been applied to monitor power infrastructure, including power lines, poles, pylons, and power stations, through all phases of electric grid development (Xiang, 2019).

A summary of sources follows:

- Ref 17: In a demonstration project, the Minnesota Department of Transportation (Wells and Lovelace, 2016) utilized UAV to inspect the Blatnik Bridge that crosses the St. Louis River. The UAV performance was compared to standard, hands-on inspection in terms of cost and time, access methods, and data collection. The cost comparison was based on the approach spans only. The fracture critical main truss spans required a hands-on inspection. Benefits of the UAV inspection included the ability to fly under the bridge and view the underside of the deck. The image quality was comparable to a close-up photograph. The ability to fly close to the bridge also proved highly beneficial. On the other hand, UBIT inspections potentially endangered the public and inspectors, added additional weight to the bridge, congested traffic lanes, and required skilled and qualified workers to operate them. The UAV approach yielded a potential cost savings of up to 66 percent or roughly $40,000.
- Ref 18: The UAV company, Wingtra, reported on the Norwegian Public Roads Administration's use of drones for surveys during road construction. UAV costs significantly reduced both the time and expense of their projects. Post-processing for all methods was not included.

**Analogous Costs and Parametric Cost Estimates for Road & Bridge Inspections: Costs Per Linear Foot (US$)**

| Ref | Visual Inspection | Terrestrial Laser Scanner LiDAR | Manned Aircraft | UAV Photogrammetry |
|---|---|---|---|---|
| 17 | $7.38 | | | $2.51 |
| 18 | | $0.32 | $0.67 | $0.06 |
| Single Point or Statistical Mean Cost Estimate | **$7.38** | **$0.32** | **$0.67** | **$1.29** |

Empirical   Reported

# Cultural and Archaeological Heritage

UAVs are also frequently employed to produce high-quality 3D models for preservation, documentation, and management of cultural heritage sites. UAV-borne sensors allow for the acquisition of data at close range, from multiple angles of view, even in largely inaccessible places. Making 3D reconstruction and visualization of large scale and tall cultural relics with photorealistic representation has become easier and quicker with relatively low-cost UAV technology. Many of these 3D models have found their way to geoportals and websites, providing the public an opportunity to "visit" via virtual tours. (Wojciechowska, 2019)

UAVs are utilized to conduct photogrammetric surveys and mapping for documenting and preserving archaeological sites. They're also commonly used with spectroradiometers and digital or thermal cameras to detect, discover, and inventory artifacts.

- Ref. 19: Orengo and Garcia-Molsosa (2019) described the first proof of concept for the automated recording of surface distributions of archaeological material across large areas using high-resolution drone imagery, photogrammetry, and a combination of machine learning and geospatial analysis. The UAV method documented almost five times more ceramic fragments, 9.5 times faster (in accumulated surveyors' times) than the traditional pedestrian survey method.

- Ref. 20: Hill (2019) compared multiple strategies for drone data collection at a test site in New Hampshire. His results demonstrated low-cost methods using DIY-style drones and post-processed kinematic GNSS data recording can increase fieldwork efficiency and produce high-resolution ortho-imagery with better than decimeter accuracy without the need for ground control.

**Analogous Costs and Parametric and Non-Parametric Cost Estimates for Archaeology (US$)**

| Ref | Pedestrian Survey | UAV Photogrammetry | PPK Enabled Fixed Wing Drone |
|---|---|---|---|
| 19 | 22 hours/Plot<br>5 m plot line spacing | 19 minutes/Plot<br>5 m plot line spacing | |
| 20 | | | $1,680 - $2,895 |

Empirical    Problematic Value (see footnote)

# Extractive Industries

Oil and gas pipelines must be monitored and inspected regularly to minimize supply risks and environmental disasters. To minimize threats from surrounding natural and anthropogenic features, it's also necessary to assess any potential hazards along the length of the pipeline and within 20 meters of it.

Monitoring and inspection of energy infrastructure is primarily done with helicopters, small planes, and foot patrols. In remote areas or regions with extreme weather, these efforts can be difficult and extremely expensive. Satellites mitigate some of these challenges, but clouds can obscure data acquisition. UAVs, in contrast, offer the advantages of high endurance and flexibility.

UAVs are now being used to map pipelines and the surroundings, identify corrosion and damage, monitor soil movement, and detect hydrocarbon leaks, oil slicks, and theft (Pajares, 2015). Industry has also taken renewed interest in the use of drones in surface and underground mines. Many mines are large and located in remote, mountainous terrain, making monitoring by traditional methods challenging. UAVs are now frequently used to map, monitor, and assess mine areas and their surroundings (Xiang, 2019).

Perhaps due to the industries' competitive nature, cost data for UAV monitoring of oil and gas infrastructure is largely unavailable. However, the techniques are the same as those used in 'Infrastructure', with additional overlap with 'Flooding' (with respect to DEM mapping). Volumetric removal cost estimates follow:

**Analogous Costs and Non-Parametric Cost Estimates for Stockpile Measurements & Volumetric Compliance: Cost Per Fixed Area Survey**

| Ref | Manned Aircraft DEM | UAV SfM/DEM |
|---|---|---|
| 21 | $10,000 | $120 |
| Single Point Cost Estimate | **$10,000** | **$120** |

Empirical    Problematic Value (see footnote)

# Air Quality

Aerosols, ozone, and gaseous pollutants affect air quality and human and environmental health. Quantifying these impacts requires continuous air quality assessments to document the concentrations and characteristics of these pollutants and environmental parameters such as temperature, wind speed, and turbulence, among others. The spatial and temporal resolution of data from ground, manned aircraft, and satellite are generally too low for local and regional applications (Pajares, 2015).

UAVs can provide more accurate information on aerosol distribution throughout the atmospheric column, which is needed to better understand air composition and quality in specific atmospheric layers (Villa et al., 2016). Compared to land-based methods, UAVs increase operational flexibility and resolution by covering larger areas and opening up remote, difficult to access, or dangerous locations to safe monitoring (Villa et al., 2016).

UAV application to air quality monitoring is still relatively new, and the body of literature is thus rather small. In many cases, cost data is intentionally excluded. For example, the EPA has stated "cost information is not reported here, as the market prices of sensors are at the purview of the manufacturer or distributors, and may change with time or purchasing volume."

A range of cost values is presented below, based on the following sources:

- Ref. 17: Aydogan Ozcan, a professor of electrical and computer engineering and bioengineering at UCLA, utilizes drones for three-dimensional air quality monitoring using a light-weight mobile imaging system. In an interview with *Inside Unmanned Systems*[6] (2017) he indicated that air sampling stations typically use beta-attenuation monitoring or tapered element oscillating microbalance instruments at a cost of $50,000 to $100,000, both of which require regular system maintenance every few weeks by highly-trained technicians. Portable particle counters cost roughly $2,000 to $8,000, but only sample the air at rates of less than 2 to 3 liters per minute. Ozcan's device can screen 13 liters of air per minute and "generates microscopic images of scanned particulate matter, providing statistics of particle size and density distribution with a sizing accuracy of roughly 93 percent".
- Ref. 18: In a progress report by the EPA, Williams (2018) shared the cost of complete or component, low-cost particulate matter sensors ranged from $25 to $2,500. Meteorological sensors ranged from $30 to $1,500. And air toxic and other sensors ranged from $50 to $2,000.
- Ref. 19: The staff of EPA's National Exposure Research Laboratory estimated the cost of FRM/FEM reference monitors (air sampling stations) at $15,000 to $50,000 and low-cost sensors at $100 to $2,500.
- Ref 20: Al-Hajjaji et al. (2017) reported on a Qatari team's efforts to develop a fixed-wing UAV system equipped with air quality sensors that collect and transmit data, and provides a platform to see and visualize all the collected measurements in an easy and user-friendly fashion. A full breakdown of component costs was included in the report.
- Ref. 21: Calderon (2019) described a number of air quality sampling units for UAVs or UAVs with an integrated gas detector. These include the Scentroid DR1000, which can be used to sample and analyze the surrounding air up to 150 m above ground level, and Boreal Laser's GasFinder2. Both

[6] https://insideunmannedsystems.com/fighting-air-pollution-fly/

companies require a formal request for quotation to share cost data. Calderon describes a potential issue with sampling with rotorcrafts, namely that downwash – airflows beneath the rotors – strongly disturbs gas distribution near the drone, which can impact utility of gas sensor data.

**Analogous Costs for Air Quality Monitoring: Fixed Costs (US$)**

| Ref | Portable Particle Counters "Low-Cost Sensors" | Air Sampling Station: Beta-Attenuation Monitoring or Tapered element oscillating microbalance | Air Quality Sampling Units for UAV |
|---|---|---|---|
| 22 | $2,000 - $8,000 | $50,000 - $100,000 | |
| 23 | $25 (component) - $2,500 | | |
| 24 | $100 - $2,500 | $15,000 - $50,000 | |
| 25 | | | $400 sensors +$4,106 drone + extras |
| 26 | | | Scentroid DR1000 Boreal GasFinder2 |
| Fixed Cost Per Unit (Range) | **$25 (component) - $2,500** | **$15,000 - $100,000** | **<$2,500 + cost of the drone** |

Empirical Reported Inflated

# Water Quality

Regularly monitoring water quality – including contaminants, sediments, and algal blooms – is vital for resource protection and management, early response, and decision making. Traditionally, technicians collect water samples using 'grab sampling' from the shoreline or the side of a boat. Statically deployed collection systems and autonomous surface or underwater vehicles (ASV or AUV, respectively) are also employed.

Many of these methods are relatively slow, spatially restricted, expensive, or difficult to deploy; none can overcome barriers, such as land or dams. To overcome these limitations, Ore et al. (2013) developed a UAV-based water sampling system that could safely fly close to the water and collect three 20 ml samples per flight. Water properties of their UAV-collected samples matched those collected through traditional manual sampling techniques, in 1/6 the amount time.

UAV-based instruments are now being successfully deployed for a wider variety of water quality-related assessments, including mapping submerged aquatic vegetation, surveying intertidal reefs systems, monitoring harmful algal blooms (Becker et al., 2019), assessing turbidity (Larson et al., 2018), detecting oil spills, and estimating cyanobacteria concentrations.

- Ref. 22: Becker et al. (2019) deployed two different low-cost, boat-launchable UAV systems instrumented with Ocean Optics STS hyperspectral Vis-NIR spectroradiometers. The University-developed systems generated high quality, low cost, very high spatial resolution (cm to m scale measurements) hyperspectral data. The system developed in-house at the University of Toledo cost under $2,000. The UAV system deployed by Michigan Tech Research Institute cost under $7,000. UAV systems such as these offer the advantages that they can be consistently flown at low altitude and below cloud cover, and deployed on extremely short notice.

- Ref. 23: In a first-of-its-kind field trial, the Government of Ireland examined whether drones could offer a quicker, cost-effective, less labor-intensive, and safer protocol for open lake water sampling (Lally et al., 2020). In a detailed cost-benefit analysis, the team found the capital investment costs for boat sampling were 1.2 to 1.5 times lower than those required for drone water sampling. However, UAV water sampling was found to be 2.3 to 3.4 times faster (in person-minutes) than boat sampling. Moreover, drone water sampling reduces both risks to personnel health and safety and offers a unique opportunity to sample unmonitored lakes and other water bodies worldwide.

**Analogous Costs for Water Quality Monitoring: Fixed Costs (US$)**

| Ref | Boat Water Sampling | UAV<br>Spectroradiometer and flight controls in waterproof chassis |
|---|---|---|
| 27 | | $2,000 (1), $7,000 (2) |
| 28 | $51.88/sample | $63.51/sample \| $13,854 |
| Fixed Cost<br>Per Unit (Range) | | **$2,000 - $13,854** |
| Single-Point Parametric Cost Estimate | **$51.88/sample** | **$63.51/sample** |

☐ Empirical

# CONCLUSIONS

Given the dearth of available cost data, the number of study areas, and the variety of environmental contexts, scales, constraints, and variables that could be assessed with UAV systems, it's impractical to provide estimates with any measure of confidence. However, it is possible to systematically review and present the fragmented data on cost of UAV collection and analysis to identify a broad cost/effectiveness range of applications and ultimately help better inform decisions.

# REFERENCES

Al-Hajjaji K, Ezzin M, Khamdan H and Hassani H 2017 Design Development and Evaluation of a UAV to Study Air Quality in Qatar Senior Design Project Report Department of Electrical Engineering Qatar University

Annis A, Nardi F, Petroselli A, Apollonio C, Arcangeletti E, Tauro F, Belli C, Bianconi R, Grimaldi S. UAV-DEMs for Small-Scale Flood Hazard Mapping. Water. 2020; 12(6):1717.

Backes, D.; Schumann, G.; Teferele, F.N.; Boehm, J. Towards a High-Resolution Drone-Based 3D Mapping Dataset to Optimise Flood Hazard Modelling. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.—ISPRS Arch. 2019, 42, 181–187.

Baena S., Boyd D.S., Moat J., (2018) UAVs in pursuit of plant conservation – real World experiences. Ecological Informatics, 47: 2-9.

Becker, B. H. et al., "Unmanned aerial system based spectroradiometer for monitoring harmful algal blooms: a new paradigm in water quality monitoring," J. Great Lakes Res. 45, 444–453 (2019).

Brunier, G.; Fleury, J.; Anthony, E.J.; Gardel, A.; Dussouillez, P. Close-range airborne Structure-from-Motion Photogrammetry for high-resolution beach morphometric surveys: Examples from an embayed rotating beach. Geomorphology 2016, 261, 76–88.

Calderon, JB. 2019. Signal Processing and Machine Learning for Gas Sensors: Gas Source Localization with a Nano-Drone. Ph.D. Dissertation. Universitat de Barcelona.

Conlin, M.; Cohn, N.; Ruggiero, P. A Quantitative Comparison of Low-Cost Structure from Motion (SfM) Data Collection Platforms on Beaches and Dunes. J. Coast. Res. 2018.

Ellenberg, A., Kontsos, A., Moon, F., and Bartoli, I. (2016) Bridge related damage quantification using unmanned aerial vehicle imagery. Struct. Control Health Monit., 23: 1168– 1179. doi: 10.1002/stc.1831.

Glendell, M., McShane, G., Farrow, L., James, M. R., Quinton, J., Anderson, K., Evans, M., Benaud, P., Rawlins, B., Morgan, D., Jones, L., Kirkham, M., DeBell, L., Quine, T. A., Lark, M., Rickson, J., and Brazier, R. E. (2017) Testing the utility of structure-from-motion photogrammetry reconstructions using small unmanned aerial vehicles and ground photography to estimate the extent of upland soil erosion. Earth Surf. Process. Landforms, 42: 1860– 1871. doi: 10.1002/esp.4142.

Groves, P. A., B. Alcorn, B., M. M. Wiest, J. M. Maselko, and W. P. Connor. Testing unmanned aircraft systems (UASs) for salmon spawning surveys. FACETS. doi:10.1139/facets2016-0019 (2016).

Hill, A. C. "Economical Drone Mapping for Archaeology: Comparisons of Efficiency and Accuracy", Journal of Archaeological Science: Reports, Vol. 24, pp. 80-91, 2019.

Inoue T., Nagai S., Yamashita S., Fadaei H., Ishii R., Okabe K., Taki H.,

Honda Y., Kajiwara K., Suzuki R. (2014) Unmanned Aerial Survey of Fallen Trees in a Deciduous Broadleaved Forest in Eastern Japan. PLoS ONE, 9(10): e109881.

Kienholz, C., Pierce, J., Hood, E., Amundson, J., Wolken, G., Jacobs, A., et al. (2020). Deglacierization of a marginal basin and implications for outburst floods, Mendenhall Glacier, Alaska. Front. Earth Sci. 8, 137. doi:10.3389/feart.2020.00137

Lally, H., O'Connor, I., Broderick, L., Broderick, M., Jensen, O., Graham, C. (2020) Assessing the Potential of Drones to Take Water Samples and Physicochemical Data from Open Lakes. EPA Research. 341.

Larson, M. D., Milas, A. S., Vincent, R. K. & Evans, J. E. (2018) Multi-depth suspended sediment estimation using high-resolution remote-sensing UAV in Maumee River, Ohio, International Journal of Remote Sensing, 39:15-16, 5472-5489, DOI: 10.1080/01431161.2018.1465616

Mancini, F., M. Dubbini, M. Gattelli, F. Stecchi, S. Fabbri, and G. Gabbianelli, 2013. Using unmanned aerial vehicles (UAV) for high-resolution reconstruction of topography: The structure from motion approach on coastal environments, Remote Sensing, 5:6880–6898.

Manfreda, S.; McCabe, M.; Miller, P.; Lucas, R.; Pajuelo Madrigal, V.; Mallinis, G.; Ben Dor, E.; Helman, D.; Estes, L.; Ciraolo, G.; et al. On the Use of Unmanned Aerial Systems for Environmental Monitoring. Remote Sens. 2018, 10, 641.

Månsson J., Hauser C., Andrén H., Possingham H. (2011). Survey method choice for wildlife management: the case of moose Alces alces in Sweden. Wildlife Biology 17: 176–190. http:// dx.doi.org/10.2981/10-052.

Matese, A.; Toscano, P.; Di Gennaro, S.F.; Genesio, L.; Vaccari, F.P.; Primicerio, J.; Belli, C.; Zaldei, A.; Bianconi, R.; Gioli, B. Intercomparison of UAV, Aircraft and Satellite Remote Sensing Platforms for Precision Viticulture. Remote Sens. 2015, 7, 2971-2990.

Messinger M., Asner G.P., Silman M. (2016) Rapid Assessments of Amazon Forest Structure and Biomass Using Small Unmanned Aerial Systems. Remote Sensing, 8(8): 615.

Michez A., Piégay H., Lisein J., Claessens H., Lejeune P. (2016b) Classification of riparian forest species and health condition using multi-temporal and hyperspatial imagery from unmanned aerial system. Environ Monitoring and Assessment, 188: 146.

Mourato, S.; Fernandez, P.; Pereira, L.; Moreira, M. Improving a DSM Obtained by Unmanned Aerial Vehicles for Flood Modelling. IOP Conf. Ser. Earth Environ. Sci. 2017, 95.

Müllerová J., Brůna J., Bartaloš T., Dvořák P., Vítková M., Pyšek P. (2017) Timing Is Important: Unmanned Aircraft vs. Satellite Imagery in Plant Invasion Monitoring. Front Plant Sci 8:887

Navarro, A., Young, M., Allan, B., Carnell, P., Macreadie, P., Ierodiaconou, D., 2020. The application of unmanned aerial vehicles (uavs) to estimate above-ground biomass of mangrove ecosystems. Remote Sens. Environ. 242, 111747.

Nowak, M.M.; Dziób, K.; Bogawski, P. Unmanned Aerial Vehicles (UAVs) in environmental biology: A review. Eur. J. Ecol. 2019, 4, 56–74.

Orengo, H. A. and Garcia-Molsosa, A., "A brave new world for archaeological survey: Automated machine learning-based potsherd detection using high-resolution drone imagery," J. Archaeological Sci., vol. 112, Dec. 2019, Art. no. 105013.

Pajares, G. (2015). Overview and current status of remote sensing applications based on unmanned aerial vehicles (UAVs). Photogram. Eng. Remote Sensing 81, 281–329. doi: 10.14358/PERS.81.4.281

Paneque-Gálvez, J.; Vargas-Ramírez, N.; Napoletano, B.M.; Cummings, A. Grassroots Innovation Using Drones for Indigenous Mapping and Monitoring. Land 2017, 6, 86.

Ruggles, S., Clark, J. and Franke, K. W., 2016. Comparison of SfM computer vision point clouds of a landslide derived from multiple small UAV platforms and sensors to a TLS based model. Journal of Unmanned Vehicle Systems, 4: 246–265.

Sankey, T., J. Leonard, and M. Moore.2019. Unmanned aerial vehicle  Based rangeland monitoring: examining a century of vegetation changes. Rangel. Ecol. Manag. 72, 858–863

Shang S., Lee Z., Lin G., Hu C., Shi L., Zhang Y., Li X., Wu J., Yan J. (2017) Sensing an intense phytoplankton bloom in the western Taiwan Strait from radiometric measurement on a UAV. Remote Sensing of Environment, 198: 85-94.s

Skrzypietz, T. 2012. Unmanned aircraft systems for civilian missions, BIGS Policy Paper, No. 1. Brandenburg Institute for Society and Security, Potsdam, GE. Available from http://www.bigs-potsdam.org/images/Policy%20Paper/PolicyPaper-No.1_Civil-Use-of-UAS_ Bildschirmversion%20interaktiv.pdf [accessed 28 January 2015].

Sturdivant, E.J.; Lentz, E.E.; Thieler, E.R.; Farris, A.S.; Weber, K.M.; Remsen, D.P.; Miner, S.; Henderson, R.E. UAS-SfM for Coastal Research: Geomorphic Feature Extraction and Land Cover Classification from High-Resolution Elevation and Optical Imagery. Remote Sens. 2017, 9, 1020.

U.S. Environmental Protection Agency. How to Evaluate Low-Cost Sensors by Collocation with Federal Reference Method Monitors. National Exposure Research Laboratory.

Villa, T. F., Gonzalez, F., Miljievic, B., Ristovski, Z. D. and Morawska, L. An overview of small unmanned aerial vehicles for air quality measurements: Present applications and future prospectives, Sensors, vol. 16, no. 7, p. 1072, 2016.

Watts, A.C.; Perry, J.H.; Smith, S.E.; Burgess, M.A.; Wilkinson, B.E.; Szantoi, Z.; Ifju, P.G.; Percival, H.F. Small unmanned aircraft systems for low-altitude aerial surveys. J. Wildl. Manage. 2010, 7, 1614–1619.

Weissensteiner, M. H., Poelstra, J. W. & Wolf, J. B. W. Low-budget ready-to-fly unmanned aerial vehicles: an effective tool for evaluating the nesting status of canopy-breeding bird species. J. of Avian Biol. 46, 425–430, doi: 10.1111/jav.00619 (2015).

Wells, J. and Lovelace, B. (2017) Unmanned Aircraft System Bridge Inspection Demonstration Project Phase II. Minnesota Department of Transportation.

Wen, Q., H. He, X. Wang, W. Wu, L. Wang, F. Xu, P. Wang, T. Tang, and Y. Lei, 2011. UAV remote sensing hazard assessment in Zhouqu debris flow disaster, Proceedings of SPIE 8175, Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions, 817510, 8 p.

Wojciechowska, G. (2019). Case Studies on the Use of UAV's for Documentation of Cultural Heritage, Archives of Photogrammetry, Cartography and Remote Sensing, 31(1), 65-73. doi: https://doi.org/10.2478/apcrs-2019-0005

Xiang, T., Xia, G., Zhang, L. "Mini-Unmanned Aerial Vehicle-Based Remote Sensing: Techniques, applications, and prospects," in IEEE Geoscience and Remote Sensing Magazine, vol. 7, no. 3, pp. 29-63, Sept. 2019, doi: 10.1109/MGRS.2019.2918840.

Yuan C., Zhang Y., Liu Z. (2015) A survey on technologies for automatic forest fire monitoring, detection, and fighting using unmanned aerial vehicles and remote sensing techniques. Canadian Journal of Forest Research, 45(7): 783-792.

# APPENDIX E: CONTRACTUAL CONSIDERATIONS - EXAMPLE OF PROFESSIONAL SERVICES LANGUAGE

**DISCLAIMER:** *The accompanying Professional Services Memorandum of Agreement template, per the State of Alaska's governing laws, is for* ***Example Purposes ONLY****.* ***Before finalizing the document, Contractor should seek legal advice to ensure all sections are legally applicable.***

***Note:*** *If Contractor is a Tribal entity,* ***special attention should be paid with regards to ownership of pre-existing materials and final products*** *as outlined in both Section XI. Confidentiality and Section XII. Work Product Ownership Except As Provided Herein.*

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## EXAMPLE

**Professional Services between XXXXX and XXXXX**
**Memorandum of Agreement for [Type of Monitoring]**

This Memorandum of Agreement (Agreement) is made on _________________, the **Effective Date,** by and between [Insert Name and Address of Entity #1]4, hereinafter "Contractee" and [Insert Name and Address of Entity #2], the "Contractor".

The Parties hereby bind themselves under this Agreement in accordance with the following terms and conditions:

**I. TERM.**

This Agreement shall take effect on the (Insert **start d**ate**)** and shall remain in force until [Insert End Date] unless terminated and/or modified in accordance with **Section IX. Terminatio**n of this Agreement.

**II. DEFINITIONS.**

"**Baseline Profile**": A baseline profile is a formal data collection event over the area of interest to begin the monitoring time series.

"**Base Flood Elevation**": A Base Flood Elevation (BFE) shows the path of riverine flood flows on the Flood Insurance Rate Map (FIRM) and is an accurate representation of the distance between cross sections, structures, nodes or grids in the hydraulic model.[2]

"**Data Products**": The digital and hard copy data products created from UAS-collection efforts to quantify landscape and/or seascape changes.

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[2] FEMA. Guidance for Flood Risk Analysis and Mapping: Profile Baseline Guidance. November 2015, https://www.fema.gov/media-library-data/1449866037723-3eca22b9c4401c2ec2eb63fa07b2c7df/Profile_Baseline_Guidance_Nov_2015.pdf.

"**Digital Elevation Models**": Digital Elevation Models (DEMs) are arrays of regularly spaced elevation values referenced horizontally either to a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system. The grid cells are spaced at regular intervals along south to north profiles that are ordered from west to east.[3]

"**Pre-Existing Materials**": Any and all materials, information, inventions, methods, procedures, and technology owned or developed by Contractor or Contractee prior to the Effective Date.[4]

"**Protocol**": The official procedure or system of rules governing scientific data collection, analysis, data/process integration into community monitoring workflows, and Federal Aviation Administration (FAA) regulations pertaining to unmanned aircraft systems (UAS).

**"Raw Data"**: The actual data files, metadata files and flight logs developed as part of UAS data collection efforts unless otherwise defined and agreed to in writing by both parties.

"**Scientific Study Area(s)**": Scientific areas of study that have been identified in flux due to current climate change conditions, and represent the measurable and significant landscape/seascape changes that will impact the Norton Sound and Alaska regions over time, including but not limited to the following: Coastal Erosion Monitoring; Flood Preparation (river and sea); Cultural and Historical Site Identification and Monitoring; Extractable Resource Identification and Monitoring; Air Quality Monitoring; Water Quality Monitoring; Wildlife Surveys; Plant Community Monitoring; and Infrastructure Monitoring.

"**Unmanned Aircraft System**": Unmanned Aircraft System (UAS) includes unmanned aircraft, equipment to control remotely, payload (e.g. camera and/or sensor), and other accessories (e.g. camera filters, payload framework, carbine blades, blade guards, etc.).

## III. GOALS AND OBJECTIVES.

The specific scientific area(s) of study, as identified in **Appendix A: Scientific Study Areas Matrix - Checklist of Monitoring Services Requested,** are to help assess landscape/seascape changes impacting the [Specify the location or region] region. This Agreement will focus on [Insert Scientific Study Area(s) Monitoring] utilizing the proposed Unmanned Aircraft System that has specific functionality to answer distinct facets of the studies at hand.

The Parties to this Agreement shall abide by the terms of this Agreement to achieve the following goals and objectives:

> *Support current and future ocean and coastal management planning and long-term resilience through the implementation of rigorous, localized and on-going UAS data collection, analysis, and training program(s) and protocol(s) for the [Specify the location or region] region or location.*

[3] USGS. "*What are digital elevation models (DEMs)*?" https://www.usgs.gov/faqs/what-are-digital-elevation-models-dems?qt-news_science_products=0#qt-news_science_products.

[4] Based definition found at: https://www.lawinsider.com/dictionary/pre-existing-materials.

## IV. OBLIGATIONS OF THE PARTIES.

The Parties shall adhere to:

1. Contractor shall:
   a) Update and educate Contractee on the current technology, protocols, and equipment/data storage requirements; and

**Paragraph "b)" below is an example of Obligations language that could be used for Coastal Erosion. Obligations language for other Scientific Study Areas can be found in the [Contractual Consideration] Appendix and copied and inserted below.**

   b) As related to **Coastal Erosion** [**and/or other Scientific Study Area**], Contractor agrees to identify, quantify, and provide landscape and/or seascape changes data; including the provisions of:
      i. Baseline profile of [Insert area of interest (e.g. land and coastal area)];
      ii. Base Flood Elevation if relevant to Scientific Study Area;
      iii. Digital elevation models used in analyses;
      iv. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
      v. Raw data collected over area of interest;
      vi. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data, as provided by **Section IV. Obligations of Parties, Subsection 3** and **Section XII. Work Product Ownership Except As Provided Herein);** and
      vii. Back-up archive of all data and products.

2. Contractee shall perform the following obligations:
   a) Be aware of the available technology, potential protocols, and equipment/data storage requirements.
   b) Provide timely communications response.
   c) Provide Traditional Ecological Knowledge (TEK) of area of interest, as needed.
   d) Provide access to the area of interest for flights (e.g. permissions, transportation, housing support).

3. Contractor and Contractee agree in writing, signed by both parties, to the protocol and specific data to be collected and as indicated and attached as **the [Contractual Consideration] Appendix C**, **Scientific Study Areas Protocols and Data Collection.**

## V. RELATION OF THE PARTIES.

The nature of the relationship between Contractee and Contractor is that of two independent contractors working together to achieve a common goal.

## VI. CONSIDERATION.

This Agreement is being made in consideration of the following:

Contractee agrees to pay the Contractor a sum of $XXXXX for completing all obligations under this agreement, unless modified in accordance with **Section IX. Termination**.

## VII. REPRESENTATIONS AND WARRANTIES.

Each party to this Agreement represents and warrants to the other party that he/she/it:

a) Has full power, authority and legal right to execute and perform this Agreement;
b) Has taken all necessary legal and corporate action to authorize the execution and performance of this Agreement;
c) This Agreement constitutes the legal, valid and binding obligations of such party in accordance with its terms; and
d) Shall act in good faith to give effect to the intent of this Agreement and to take such other action as may be necessary or convenient to consummate the purpose and subject matter of this Agreement.

## VIII. INDEMNIFICATION/HOLD HARMLESS.

1. Contractor agrees to indemnify and save harmless the Contractee, its properties and employees, hereinafter in this Paragraph included in the term "Contractee" from any and all costs, expenses, damages, liens, charges, claims, demands or liabilities whatsoever arising out of or in any manner connected with or resulting from the operations hereunder of Contractor, its servants, employees, independent contractors and assigns, as the case may be, which may be asserted by any third party whatsoever. Contractor at its own cost and expense, shall defend against any and all actions, suits or other legal proceedings that may be brought or instituted against the Contractee on any such claim or demand and shall pay or satisfy any judgment or decree, including attorney's fees, that may be rendered against the Contractee in any such action, suit or legal proceeding or which may result therefrom.

2. The Contractee agrees to indemnify and save harmless the Contractor, its properties and employees, hereinafter in this Paragraph included in the term "Contractor" from any and all costs, expenses, damages, liens, charges, claims, demands or liabilities whatsoever arising out of or in any manner connected with or resulting from the operations hereunder of Contractor, its servants, employees, independent contractors and assigns, as the case may be, which may be asserted by any third party whatsoever. The Contractee at its own cost and expense, shall defend against any and all actions, suits or other legal proceedings that may be brought or instituted against the Contractor on any such claim or demand and shall pay or satisfy any judgment or decree, including attorney's fees, that may be rendered against the Contractor in any such action, suit or legal proceeding or which may result therefrom.

## IX. TERMINATION.

1. The Parties may terminate this Agreement for any reason by providing at least 30 days prior written notice to the other party, provided that either party may terminate this Agreement with 7 days' prior written notice if the other party fails substantially to perform its obligations under this Agreement.

2. Either party may terminate its performance of related obligations under this Agreement if the other party fails to rectify a material breach (as provided in Section 1 above) under a portion of this Agreement within thirty (30) days of receipt by the breaching party of written notice of such breach from the non-breaching party. In such case, the non-breaching party shall be entitled, without further notice, to cancel that party's involvement pursuant to the agreement, without prejudice to any claim for damages, breach of contract or otherwise. The parties agree that the failure or termination of any portion or relevant provision of this Agreement will not be a basis for terminating other severable obligations or provisions of this Agreement, unless the failure or breach is such that the entire Agreement loses substantially all of its value to the non-breaching party.

In the event of termination, Contractor shall be paid in accordance with the compensation terms of this Agreement for services provided in accordance with the scope of services up to the date of termination and for reimbursable expenses made in reliance on the scope of work established prior to receipt of the written notice of termination.

Any termination of this Agreement shall not absolve the parties from the obligation to observe the confidentiality measures and other restraints as set out herein.

## X. REMEDIES ON DEFAULT.

In addition to any and all other rights a party may have available according to law, if a party defaults by failing to substantially perform any provision, term or condition of this Contract (including without limitation the failure to make a monetary payment when due), the other party may terminate the Agreement by providing written notice to the defaulting party. This notice shall describe with sufficient detail the nature of the default. The party receiving such notice shall have 30 days from the effective date of such notice to cure the default(s). Unless waived by a party providing notice, the failure to cure the default(s) within such time period shall result in the automatic termination of this Agreement.

## XI. CONFIDENTIALITY.

Both parties acknowledge that during the course of this Agreement, each may obtain confidential information regarding the other party. Both parties agree to treat all such information and the terms of this Agreement as confidential and to take all reasonable precautions against disclosure of such information to unauthorized third parties during and after the term of this Agreement. Subject to **Section XII. Work Product Ownership Except As Provided Herein**, below, upon request by an owner, all documents relating to the confidential information will be returned to such owner. Prior to execution of this Agreement, the Parties will agree in writing as to what information is confidential and therefore covered by this agreement.

Subject to sub-clauses a-b below, each party may disclose information that would otherwise be confidential after giving notification, including reason for said disclosure, and receiving written approval from the other party, to disclose if and to the extent:

a) Disclosure is required by the law of any relevant jurisdiction;

b) The information has come into the public domain through no fault of that party; or

The other party has given prior written approval to the disclosure.

## XII. WORK PRODUCT OWNERSHIP EXCEPT AS PROVIDED HEREIN.

Unless otherwise agreed to in writing by both parties and as provided, herein, any collected data, copyrightable works, ideas, discoveries, inventions, patents, products, or other information (collectively the "Work Product") developed in whole or in part by Contractor in connection with the identified Obligations will be the exclusive property of Contractee. Upon request, Contractor will execute all documents necessary to confirm or perfect the exclusive ownership of Contractee to the Work Product.

**Exception:**

**Title to Intellectual Property.** It is understood and agreed that the entire right, title, and interest throughout the world in and to all Intellectual Property Rights shall be and hereby are vested and assigned by Contractor to Contractee for works created under this contract, with the exclusion of rights and circumstances identified in the **Pre-Existing Rights** section below. With respect to copyrighted materials, Contractor further agrees that Contractee is assigned all rights, including the right to edit and create derivative works from the materials, and the right to any and all commercial reproduction, transmission, display, performance or distribution of the materials or any derivative works based on the materials via any means currently existing or developed or discovered in the future, including, without limitation, posting to the Internet, CD, DVD or other digital format. Contractee may put Intellectual Property Rights into the public domain or otherwise grant licenses under any terms it deems advisable in its sole discretion.

**Pre-Existing Rights.** To the extent that any of Contractor's pre-existing materials are used or adapted for the purpose of performing under this Agreement, Contractor retains ownership of such pre-existing materials. Contractor shall inform Contractee in writing when Contractor uses her or his pre-existing materials in the development and delivery of materials or works contracted by Contractee. Contractee must secure written permission to use Contractor's identified pre-existing materials from Contractor prior to the use, publication, reproduction, display, distribution, and preparation of derivative works and Contractee must cite the authorship of any such pre-existing materials in such derivative works.

Furthermore, by giving the right of use of its identified pre-existing materials, the Contractor retains equal rights to irrevocable, worldwide, unlimited, royalty-free license to use, publish, reproduce, display, distribute copies of, and prepare derivative works based upon, such pre-existing materials and derivative works thereof unless otherwise negotiated by Contractor and Contractee and agreed to in writing. The Contractor may assign, transfer, and sublicense such rights related to pre-existing material to others without Contractee's knowledge or approval.

## XIII. FORCE MAJEURE.

If performance of this Agreement or any obligation under this Agreement is prevented, restricted, or interfered with by causes beyond either party's reasonable control ("Force Majeure"), and if the party unable to carry out its obligations gives the other party prompt written notice of such event, then the obligations of the party invoking this provision shall be suspended to the extent necessary by such event. The term Force Majeure shall include, without limitation, acts of God, fire, explosion, vandalism, storm or other similar occurrence, orders or acts of military or civil authority, or by national emergencies, insurrections, riots, or wars, or strikes, lock-outs, work stoppages, or other labor disputes, or supplier failures. The excused party shall use reasonable efforts under the circumstances to avoid or remove such causes of non-performance and shall proceed to perform with reasonable dispatch whenever such causes are removed or ceased. An act or omission shall be deemed within the reasonable control of a party if committed, omitted, or caused by such party, or its employees, officers, agents, or affiliates.

**XIV. ARBITRATION.**

Any controversies or disputes arising out of or relating to this Agreement shall be resolved by binding arbitration in accordance with the then-current Commercial Arbitration Rules of the American Arbitration Association. The parties shall select a mutually acceptable arbitrator knowledgeable about issues relating to the subject matter of this Agreement. In the event the parties are unable to agree to such a selection, each party will select an arbitrator and the two arbitrators in turn shall select a third arbitrator, all three of whom shall preside jointly over the matter. The arbitration shall take place at a location that is reasonably centrally located between the parties, or otherwise mutually agreed upon by the parties. All documents, materials, and information in the possession of each party that are in any way relevant to the dispute shall be made available to the other party for review and copying no later than 30 days after the notice of arbitration is served. The arbitrator(s) shall not have the authority to modify any provision of this Agreement or to award punitive damages. The arbitrator(s) shall have the power to issue mandatory orders and restraint orders in connection with the arbitration. The decision rendered by the arbitrator(s) shall be final and binding on the parties, and judgment may be entered in conformity with the decision in any court having jurisdiction. The agreement to arbitration shall be specifically enforceable under the prevailing arbitration law. During the continuance of any arbitration proceeding, the parties shall continue to perform their respective obligations under this Agreement.

**XV. NOTICE.**

Any notice or communication required or permitted under this Agreement shall be sufficiently given if delivered in person or by certified mail, return receipt requested, to the addresses listed above or to such other address as one party may have furnished to the other in writing. The notice shall be deemed received when delivered or signed for, or on the third day after mailing if not signed for.

**XVI. ENTIRE AGREEMENT.**

This Agreement contains the entire agreement of the parties regarding the subject matter of this Agreement, and there are no other promises or conditions in any other agreement whether oral or written. This Agreement supersedes any prior written or oral agreements between the parties.

**XVII. AMENDMENT.**

This Agreement may be modified or amended if the amendment is made in writing and signed by both parties.

**XVIII. SEVERABILITY.**

If any provision of this Agreement shall be held to be invalid or unenforceable for any reason, the remaining provisions shall continue to be valid and enforceable. If a court finds that any provision of this Agreement is invalid or unenforceable, but that by limiting such provision it would become valid and enforceable, then such provision shall be deemed to be written, construed, and enforced as so limited.

**XIX. WAIVER OF CONTRACTUAL RIGHTS.**

The failure of either party to enforce any provision of this Agreement shall not be construed as a waiver or limitation of that party's right to subsequently enforce and compel strict compliance with every provision of this Agreement.

**XX. GOVERNING LAW.**

This Agreement shall be governed by, and construed in accordance with, the laws of state that the principal office of the Contractor is located.

**SIGNATORIES.**

This Agreement shall be agreed to and accepted on behalf of **Contractee** by

_____________________________________________________ Date: ______________

*Signature*

Name:

Title, Governing Body:

Address:

City, State, Zip Code

Email:

Phone:

Agreed to and accepted signed on behalf of **Contractor** by

_____________________________________________________ Date: ______________

*Signature*

Name:

Title, Governing Body:

Address:

City, State, Zip Code

Email:

Phone:

**Effective as of the date first written above.**

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**MOA Template Appendix**

MOA Template Appendix A: Scientific Study Areas Matrix - Checklist of Monitoring Services Requested

MOA Template Appendix B: Obligations of Scientific Study Area Monitoring by Contractor

MOA Template Appendix C: Scientific Study Areas Protocols and Data Collection

**DISCLAIMER:** ***Appendix A: Scientific Study Areas Matrix - Checklist of Monitoring Services Requested*** *<u>and</u>* ***Appendix B. Obligations of Scientific Study Area Monitoring by Contractor*** *below are to serve as examples. Final language should be determined and agreed to during contracting of actual services and review by legal counsel.*

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**MOA Template Appendix A: Scientific Study Areas Matrix - Checklist of Monitoring Services Requested**

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The types of Monitoring Services requested are selected in the chart below. **Contractor is <u>ONLY</u> responsible for Scientific Study Area(s) and monitoring selected below and identified under Section IV. Obligations of the Parties of this Agreement. Contractors should use the sensor(s) that is (are) efficient for performing the work, and can support the delivery of the desired data products.**

| STUDY AREA/ MONITORING | TYPE OF MONITORING SENSOR/DEVICE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Optical | LiDAR | Infrared | Multi-spectral | Hyper-spectral | In Situ Water Samplers | In Situ Gas Samplers | Particulate Matter (PM) Samplers | Other Sensor/ Device | Other Sensor/ Device |
| Coastal Erosion Monitoring | | | | | | | | | | |
| Flood Preparation | | | | | | | | | | |
| Infrastructure Monitoring | | | | | | | | | | |
| Water Quality Monitoring | | | | | | | | | | |
| Cultural & Historical Site Identification & Monitoring | | | | | | | | | | |
| Extractable Resource Identification & Monitoring | | | | | | | | | | |
| Wildlife Surveys | | | | | | | | | | |
| Plant Community Monitoring | | | | | | | | | | |
| Air Quality Monitoring | | | | | | | | | | |

**MOA Template Appendix B. Obligations of Scientific Study Area Monitoring by Contractor**

1. **Coastal Erosion Monitoring Obligation**
   Agrees to identify, quantify, and provide landscape and/or seascape changes and data, including the provision of:

   a. Base Flood Elevation;
   b. Digital elevation models used in analyses;
   c. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
   d. Raw data collected over area of interest;
   e. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
   f. Back-up archive of all data and products.

2. **Flood Preparation (river and sea) Monitoring Obligation**
   Agrees to identify areas prone to flooding, new and old, including the provision of:

   a. Base Flood Elevation;
   b. Digital elevation models of area(s) of interest:
      i. Quantification of low-lying areas to avoid during development
      ii. Identification of potential flood water channels (river and sea)
      iii. Identification of changes overtime (annual differential analyses)
   c. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
   d. Raw data collected over area of interest;
   e. Maps to support storm surge advisory warnings (river and sea)
   f. Back-up archive of all data and products.

3. **Infrastructure Monitoring Obligation**
   Agrees to identify and monitor current state of key XXXXX [Contractee specified] infrastructure including the provision of:

   a. Base Flood Elevation;
   b. Baseline infrastructure maps (presence and status);
   c. Identification and mapping of integrity anomalies of key XXXXX [Contractee specified] infrastructure:
      i. Water storage
      ii. Fuel storage (heating and transportation)
      iii. Water delivery
      iv. Roads
      v. Heat delivery
      vi. Other services delivery (e.g. electricity, communications), as identified
   d. Raw data collected over area of interest;
   e. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
   f. Back-up archive of all data and products.

4. **Water Quality Monitoring Obligation**

   Agrees to measure the spectral characteristics of water and pollutants to determine quality, including the provision of:

   a. Baseline conditions of sea water and fresh water sources;
   b. Determine seasonality of defined water quality parameters per waterbody;
   c. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
   d. Identifying and monitoring oil spills (surface area and trajectory input);
   e. Raw data collected over area of interest;
   f. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
   g. Back-up archive of all data and products.

5. **Air Quality Monitoring Obligation**

   Agrees to assess air quality for human and animal health, including the provision of:

   a. Assessment of air quality:
      i. Baseline values of stationary sources (municipal buildings as subset of region)
      ii. Measurements of known air quality disturbances (e.g. tundra fires, boats, mining equipment, oil spills, etc.)
   b. Raw data collected over area of interest;
   c. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
   d. Back-up archive of all data and products.

6. **Cultural and Historical Site Identification and Monitoring Obligation**

   Agrees to identify structures and landscape anomalies that could be cultural resources; monitoring known cultural resources for change, including the provision of:

   a. Identification of anomalous landscape features (e.g. square depressions);
   b. Identification of movement (uplift/sinking) of known historical structures (e.g. grave- yards);
   c. Baseline profile of area of concern;
   d. Base Flood Elevation;
   e. Digital elevation models used in analyses;
   f. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
   g. Raw data collected over area of interest;
   h. Identification and quantification of landscape and/or seascape changes;
   i. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
   j. Back-up archive of all data and products.

7. **Extractable Resource Mapping and Monitoring Obligation**

Agrees to map extractable resources/resources areas and monitor extraction operations, including the provision of:

a. Gravel pit or mining resource assessment
    i. Indicative geologic features for exploration (precious metals and stones, petroleum, etc.)
    ii. Components of extractable activities and failure indicators (e.g. tailings, tailing pond-levels, etc.)
b. Baseline profile;
c. Base Flood Elevation;
d. Digital elevation models used in analyses;
e. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
f. Raw data collected over area of interest;
g. Identification and quantification of landscape changes;
h. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
i. Back-up archive of all data and products.

8. **Wildlife Surveys Obligation**

Agrees to identify and map current populations of wildlife species of concern, including the provision of:

a. Establishment of population baseline for key species:
    i. Land mammals (caribou, moose, fox, beaver, others?)
    ii. Sea birds (nesting, molting, migration)
    iii. Sea mammals (whales, seals, specific whale/seal species to region, migration)
b. Development of co-management monitoring techniques using UAS;
c. Baseline profile of habitat;
d. Digital elevation models used in analyses;
e. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
f. Raw data collected over area of interest;
g. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
h. Back-up archive of all data and products.

9. **Plant Community Monitoring Obligation**

Agrees to identify current plant composition in [Insert area of interest (e.g. land and coastal area)] and monitor changes in composition and habit, including the provision of:

a. Identification and mapping of baseline plant communities in [Insert area of interest (e.g. land and coastal area)];
b. Identification of changes to significant wildlife forage species (composition, habit, vitality, NDVI);
c. Baseline profile;
d. Digital elevation models used in analyses;
e. Integration of Traditional Ecological Knowledge (TEK) of area of interest;
f. Raw data collected over area of interest;
g. Identification and quantification of landscape and/or seascape changes;
h. Data products, digital and hard copy, of analyzed data (if Contractor is responsible for delivery of analyzed data); and
i. Back-up archive of all data and products.

**MOA Template Appendix C: Scientific Study Areas Protocols and Data Collection**

Flight protocols and data collection methodologies will be specific to the Scientific Study Area that is being assessed, and will be defined on a contract by contract basis based on specific data requirements. All flight protocols will follow the guidelines set forth in 14 CFR Part 107 - Small Unmanned Aircraft Systems. All flights will be conducted by pilots flying under Part 107 certification defined in Subpart C (Remote Pilot Certification) as civil operators, or under a Certificate of Authorization as a governmental operator under the statutory requirements of 49 Code 40102(a) and 40125 for public aircraft. UAS pilots are responsible for maintaining Flight Logs for each individual UAS flight. Each log should at a minimum include date, crew, aircraft, sensors, and additional notes. It is not recommended to have UAS pilots perform UAS data management and assurance roles due to their primary requirements to fly aircraft and observe the airspace in support of safe operations. All flights will be conducted with the support of UAS visual observers to ensure public safety. Observers are responsible for scanning the airspace where the small UAS is operating, and maintaining an awareness of the position of the small UAS through direct observation. Observers must remain in communication with the pilot in command at all times and be able to coordinate collision avoidance maneuvers with the pilot in command as necessary. It is not recommended to have UAS observers perform UAS data management and assurance roles due to their primary requirements to fly aircraft and observe the airspace in support of safe operations. However, observers may be able to fulfill other mission support functions, as long as those functions do not interfere in any way with the safe observation of the airspace and aircraft in flight.

All data provisions will follow the agreed upon requirements per study area, and will include the deliverables defined in Part IV - Obligations of the Parties, of this MOU.

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**DISCLAIMER:** *The accompanying Professional Services Memorandum of Agreement template, per the State of Alaska's governing laws, is for* ***Example Purposes ONLY****.* ***Before finalizing document, Contractor and Contractee legal counsel must review the document to ensure all sections are legally applicable.***

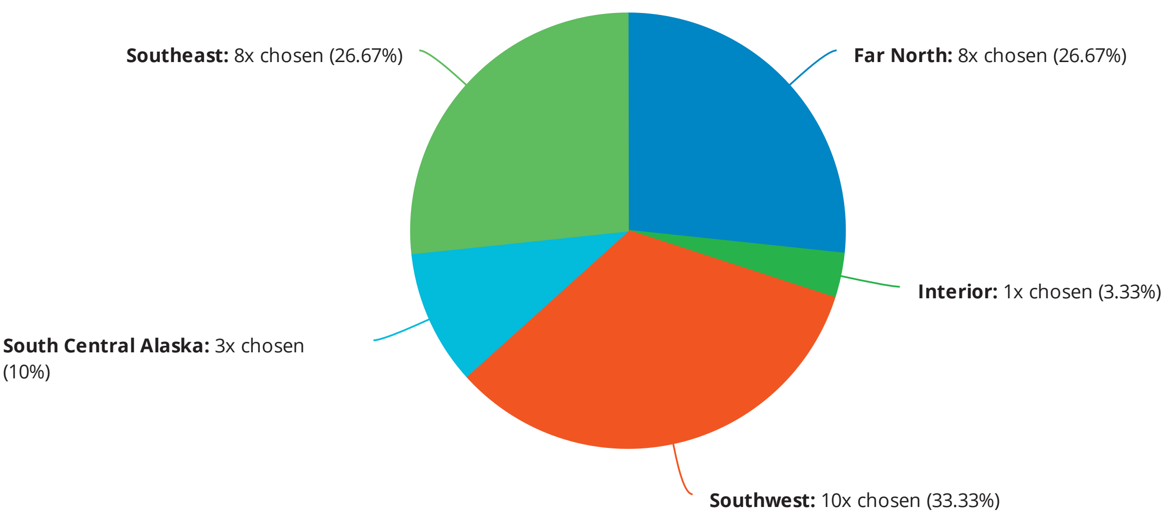
***Note:*** *If Contractor is a Tribal entity,* ***special attention needs to be paid with regards to ownership of pre-existing materials and final products*** *as outlined in both Section XI. Confidentiality and Section XII. Work Product Ownership Except As Provided Herein.*

# APPENDIX F: UNALAKLEET FEASIBILITY STUDY PROJECT SURVEY (APRIL 2020)

# 2020 Unalakleet Feasibility Study Project Survey (April 2020)

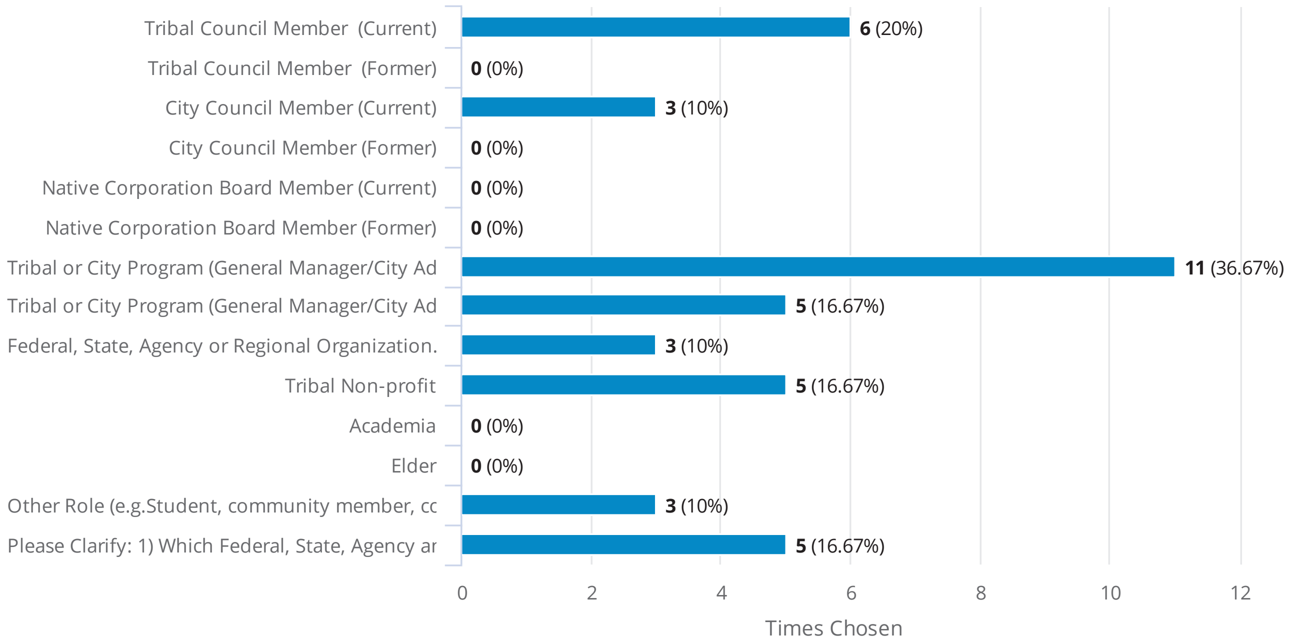
## In what region of Alaska is your community?

Number of responses: 30



## What is your role in your Community? Please check all that apply.

Number of responses: 30

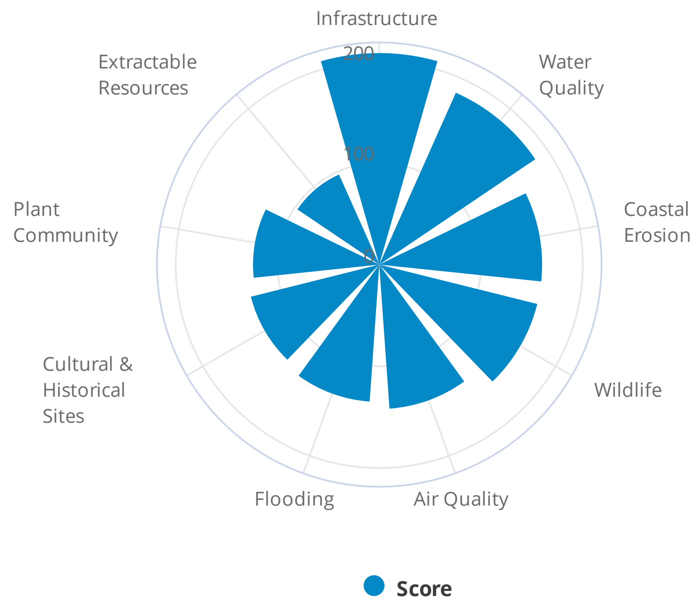



"Please Clarify: 1) Which Federal, State, Agency and/or Regional Organization you have a role; and/or 2) What you Other Role is." text answers:

| |
|---|
| Yukon River Inter-Tribal Watershed Council |
| Please Clarify: 1) Which Federal, State, Agency and/or Regional Organization you have a role; and/or 2) What you Other Role is. |
| City Clerk/Treasurer |
| City Administrator |
| Borough Employee |

## From the list below, what do you see as your community's biggest concerns? (Please rank these nine areas, 1 - Highest to 9 - Lowest.)

Number of responses: 30




## Are there other areas of climate change concern not mentioned above?

Number of responses: 15

Text answers:

Alteration of river flow regimes and effects on biological communities; effects of climate change on harmful algae blooms.

Season and weather changes.

I took 'Coastal Erosion' to mean any erosion, including river. River erosion is threatening many Yukon River Basin communities and there are few tools for communities to adapt to accelerated erosion. Good governance is also really important during times of change.

The increasing impact of permafrost degradation that affect the transportation infrastructure needs of our region and the lack of funds to address this real problem.

PFAS/PFOS
Ozone

Climate impacts our economy in how it affects salmon habitat, returns and survival. In addition, climate is impacting our ability to harvest shellfish species safely.

We have energy impacts from low water and drought conditions.

Food security and community well-being.  Because of changes in weather and ice, tribal communities are losing people to travel accidents.  These losses reawaken trauma, create food insecurity and weaken the community. Also, with changing climate, traditional foods are becoming more difficult to locate,  and in the case of shellfish, may be unsafe. (harmful algal blooms).

Yes. How our subsistence resources and environment are affected by climate change can impact our culture and traditional knowledge by altering weather patterns and conditons.

Shipping traffic and its inevitable pollution and possible destruction of marine ecology due to loss of sea ice and the opening of the NW Passage.

Ocean acidification; Sea Surface Temperature change; drought

Our subsistence way of life and the affects that global warming is on the wildlife we eat.

Noted - "Coastal" Erosion struck out on the hard copy.

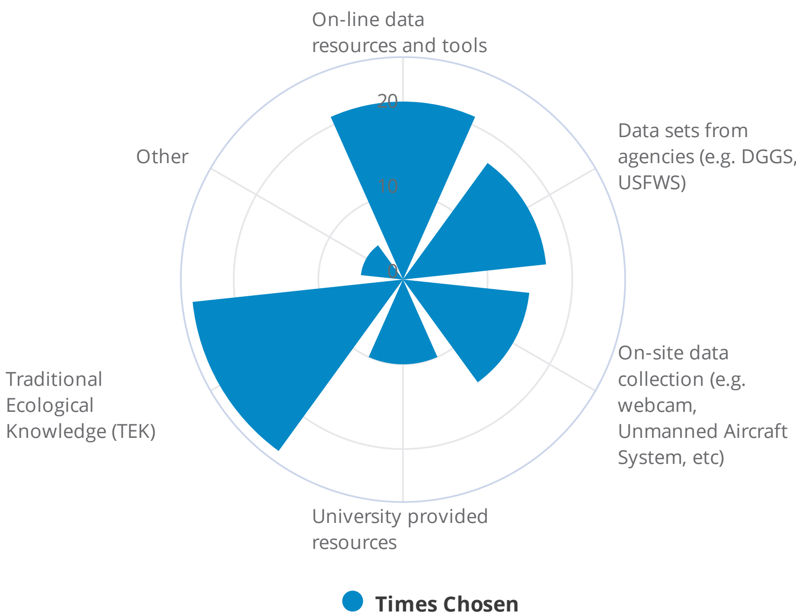
Wild fire

Subsistence sustainability/safety.  We've had years of being unable to harvest some subsistence foods due to PSP

Permafrost

## Of the nine concerns listed above, what data does your community use to make decisions about these concerns? (Please check all that apply.)

Number of responses: 28

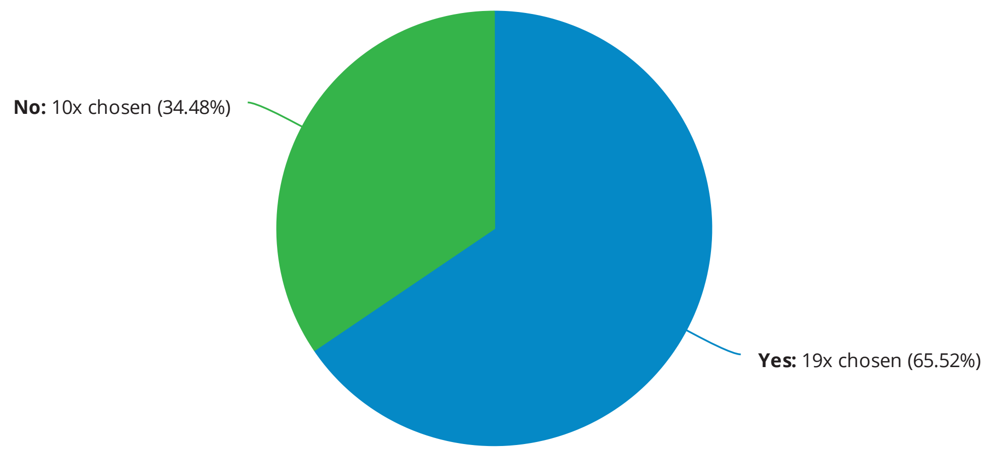



"Other" text answers:

| |
|---|
| We are starting to use UASs to monitor erosion |
| Sitka Tribe's SEATOR project. |
| Information from environmental agencies and organizations |
| we use a bi annual natural resources survey that gives the community an opportunity to help guide us in what we do by what is most important to them |
| staff generated data from research |

## Do you see gaps in the data resources used for decision-making?

Number of responses: 29




## If yes, please briefly explain the gaps that you see.

Number of responses: 19

Text answers:

Geospatial data is very informative but in rural Alaska these data are not widely available, for example accurate and precise elevation data can be used to estimate fish habitat and wildfire fuels potential but are not available for the Skagway and Dyea areas in a fine enough resolution to be useful.

More TEK analysis along with other sourced data.

We need more community collected data that is year-round and long term. If data is collected 'closer' to the issue, its use in decision making is more effective. By closer, I mean by community members and guided by Traditional Knowledge. Information is not as effective if it is collected by 'outsiders' and buried in academic online datasets that are difficult to use.

Real time data would be best if available in multispectral and LIDAR elevation data integrated in a single imagery file composed of independent multiple bands. This technology would ensure accuracy in showing actual degradation of permafrost.

Real-time, in-situ observations coupled by timely and systematic monitoring standards. What I mean is our community in Barrow, whch suffers from coastal erosion, flooding and is actively whaling and has other subsistence activities, needs a routine - say annual (ideally 4 times a year) monitoring routine which is conducted according to strict standards (resolution, data standards, etc) so we can understand what is happening in the community and make long term decisions.

Often there are a dozen organizations to look at when one needs information - BIA, FEMA, Treasury, State of AK, Borough, City, Tribal consortium.
For example, today we need to find power lines buried in some land. The city doesn't have maps. The State has plats but they are old. Reviewing some of them yields some information but not all.

the gaps are more about missing connections such as how TEK interrelates to established scientific sources

1. There are no accurate projections of sea level rise for western Alaska. 2. There are not local permafrost projections. 3. Need projections for ice and snow pack, to understand the implications for salmon from shifts from a snow pack based watershed to a rainfall based one.

The gaps may be that all the entities/community members are needing to work together in a respectable manner in order to resolve a common goal/issue that benefits the community as a whole.

Federal (and state) funding does not match the need.

Very little localized data on ambient conditions in terms of population ecology / ecological change due to stressors

Traditional Ecological Knowledge is being lost with our elders. Very little or no written documentation of the changes happening in our area.

Lack of funding.

There should be study every year, and for each season.

Need more info on air quality but we are working with National Park Service to bridge the gap.

Community-specific scientific data is needed.

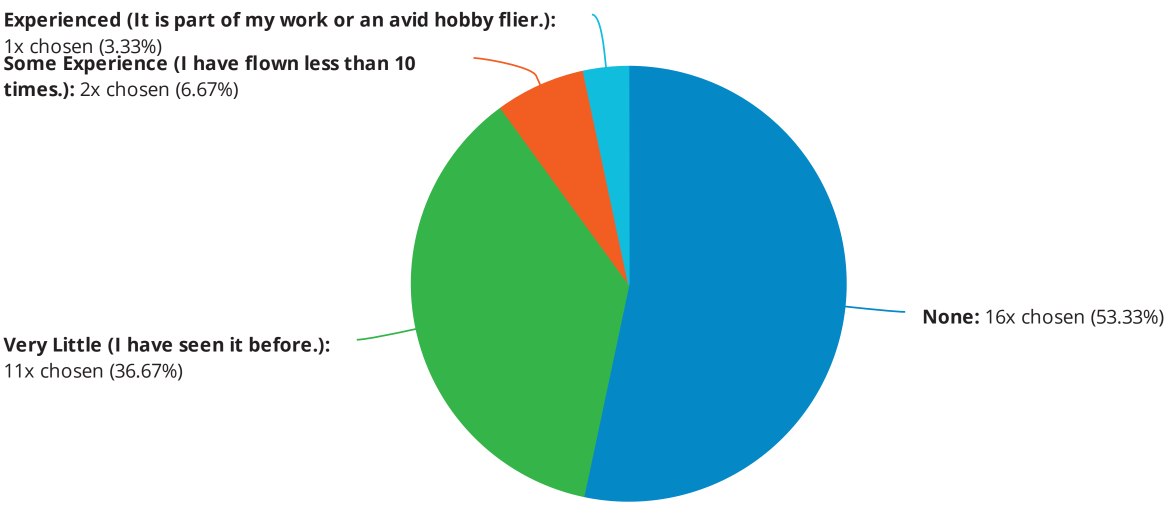
The gaps we tend to see are that we can only do a one time baseline data collection under EPA's IGAP program. When in reality you need several years of baseline before you can start to see patterns that may be helpful. There is also data mining that happens that the community never sees the results from. The scientific community, either on an agency or college level, does not write into their programs that they will come back and share or give a copy of their research reports back to the communities from where they came.

We're remote enough not many entities decide to come study in our area. Those who do, don't always utilize local experts, so they're often ineffective in their data collection, and results are not very accurate.

The transparency between different agencies and organizations on tying the information to other datasets.

## Prior Unmanned Aircraft Systems (UAS) Experience?

Number of responses: 30




## Do you have any other comments related to UAS in your community?

Number of responses: 14

Text answers:

We would like to use UAS to track harmful algae blooms, map fish habitat, assess forest health and fuel loads, estimate shellfish bed abundance, and capture river dynamic information.

I have been flying drones in rural Alaska for a couple years now, and training Tribal Environmental Professionals to use this technology. People are excited about its potential. I'm very interested in the results of your work, because we have skipped a lot of the 'desk' study and jumped right into collecting data. Not because we didn't think it was important, but because change is happening so fast there is an urgency to collecting data, and getting people training to do so. I think what you are learning in this process is really important and interesting. (Hi John!)

I think the benefits would be far reaching and encompass many more aspects of data acquisition for each of the nine scientific study areas listed.

Locals would want to be asked for permission before drones fly high enough to see over local lands.

Our Fisheries Department has been using a drone to conduct surveys for fish habitat and returns.

Potentially a great tool to assess landfills, erosion, snow pack, ice thickness.

If UAS systems are used please use in a respectable manner for a goal to make research easier taking in to consideration people's privacy and livelihood. Be aware of all life safety including birds while following safety requirements that includes commercial/private Aircrafts. Having a meeting or post the schedule to inform the public what the intents of the UAS are would be good so that there is some type of awareness, people like to know what is going on especially if it involves research and maybe they would help. Have safety tips readily available just incase perhaps the craft has malfunctioned. This would be a nice tool to help monitor rapid changes which maybe a tool to apply for grants needed.

n/a

No

With our terrain and modes of transportation Unmanned Aircraft Vehicle is a very good way to get to inaccessible area's.

No

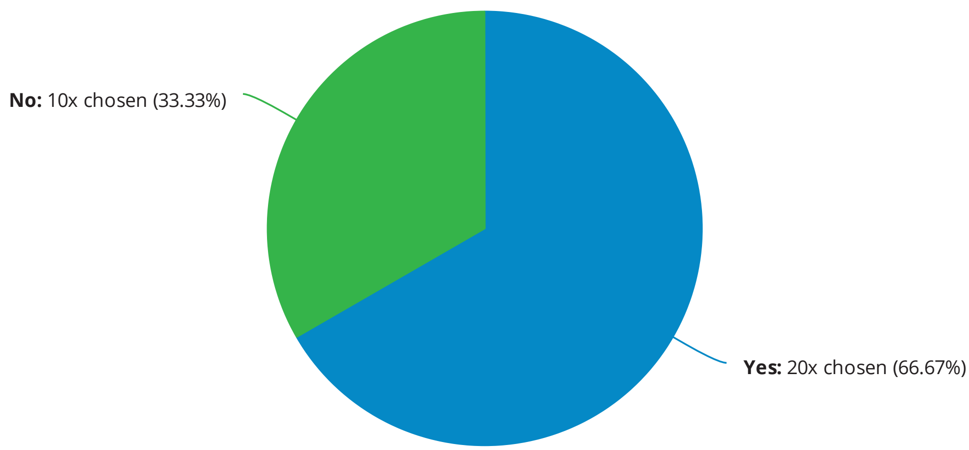
In the town proper UAS is not permitted due to the close proximity to the airport airstrip.

I think this is something we as tribes should be embracing.  We should all be learning how to use these types of data collection devices.  We are supposed to be building capacity and this would move us all further along because of the data collected could help us all to make better decisions in the future for our community and our resources.

It's been used a little in tribal projects by contractors, but the Tribe has not directly utilized it.

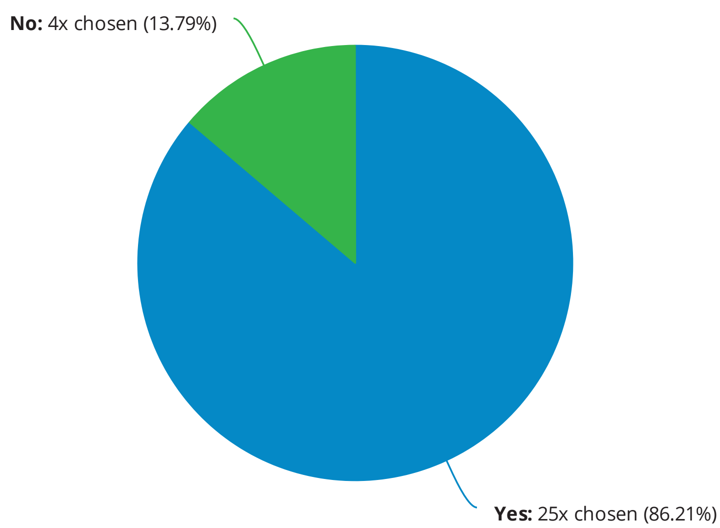
## Would you like an invite to the upcoming Webinar?

Number of responses: 30




## Interested in additional follow-up on the project?

Number of responses: 29




## Please enter your contact information if you would like to stay involved in the project (Optional):

Number of responses: 25

# APPENDIX G: ADDITIONAL RESOURCES ABOUT THE IMPACTS OF CLIMATE CHANGE ON ALASKA

**Alaska Center for Climate Assessment and Policy. "VAWS: Improving Communication of Coastal Flood Warnings to Alaska Communities" Webinar (March 13, 2019)**
https://uaf-accap.org/event/vaws-improving-communication-of-coastal-flood-warnings-to-alaska-communities/
Presented by Ed Plumb, National Weather Service, the webinar highlights success the National Weather Service has had in improving two-way communication and warnings to western Alaska communities during coastal flood events. Unalakleet and John Henry, as a Weather Ready Nation (WRN) Ambassador, are recognized for their contributions to the WRN program.

**Alaska Native Tribal Health Consortium (ANTHC) LEO Network**
https://anthc.org/what-we-do/community-environment-and-health/leo-network/
The LEO Network is a network of local environmental observers and topic experts who apply traditional knowledge, western science and technology to document significant, unusual or unprecedented environmental events in our communities. These changes can be observed in seasonality, plants and wildlife, weather conditions as well as natural hazards including coastal erosion, flooding, droughts, wildfire and other events that can threaten food security, water security and community health. The purpose of the LEO Network is to increase understanding about environmental change so communities can adapt in healthy ways.

**Alaska Sea Grant Marine Advisory Program/University of Alaska Fairbanks. Alaska Climate Change Adaptation Planning Manual for Coastal Alaskans and Marine Dependent Communities (2011)**
https://seagrant.noaa.gov/News/Article/ArtMID/1660/ArticleID/376/Alaska-Climate-Change-Adaptation-Planning-Tool- (Manual downloadable pdf at: https://seagrant.uaf.edu/bookstore/pubs/M-141.html.)
This manual is for extension professionals, community organizers, local planning officials, teachers, or anyone else whose task is to help individuals, families, businesses, communities, and local governments think through the meaning of climate change on the local scale, assess vulnerabilities, devise strategies for improving resilience, locate tools and resources that will help, and develop and implement plans for adaptation. This manual includes an eight-step process, which community members can follow to discuss ways to adapt to changes they are already experiencing or they expect in the future, and create an adaptation plan.
[Also see U.S. Climate Resilience Toolkit at: https://toolkit.climate.gov/tool/climate-change-adaptation-planning-manual-coastal-alaskans-and-marine-dependent-communities.]

**Denali Commission Village Infrastructure Protection Program**
https://www.denali.gov/programs/village-infrastructure-protection/
In 2015 the White House directed the Denali Commission to establish a Village Infrastructure Protection (VIP) Program to assist rural Alaskan communities that are threatened by erosion, flooding and permafrost degradation. The goal of the VIP Program is to mitigate the impact of these threats with respect to safety, health and the protection of infrastructure.

**International Public Health Journal, supplement. "Characteristics of a community-based sentinel surveillance system: Lessons learned from toolkit development and implementation." (2013)**
Full Cite: Sunbury, Tenaya M, PhD; Driscoll, David L, PhD. International Public Health Journal, suppl. Special issue: Lessons learned in building community..; Hauppauge Vol. 5, Iss. 1, (2013): 105-114.
https://www.researchgate.net/publication/330853775_Characteristics_of_a_community-based_sentinel_surveillance_system_Lessons_learned_from_toolkit_development_and_implementation (You will have to go through several steps to gain access to this study.)

From the study Abstract, the authors, "*...describe the challenges and steps involved in developing a sentinel surveillance system and the information it provides for improving public-health decision making. The final surveillance survey includes five thematic parts and consists of community observations on local weather, hunting and harvesting, food and water safety, general health and air quality, and any additional community observations. An understanding of climate change impacts on population health through public health surveillance is fundamental to planning and evaluating policies and programs.*"

**Mapping & Monitoring of Cemeteries with UAVs**
An example of articles on mapping cemeteries using UAVs.
- The Drone Girl. This Graveyard-Mapping Drone Marks a Major Step for North American Drone Progress. (October 31, 2018) https://thedronegirl.com/2018/10/31/graveyard-mapping-drone/
- OpusXenta. Flying the Drone: New Technologies in Cemetery Mapping (November 12, 2020) https://opusxenta.com/blog/flying-the-drone-new-technologies-in-cemetery-mapping

**NOAA Office of Response and Restoration. Environmental Response Management Application (ERMA®)**
https://response.restoration.noaa.gov/resources/maps-and-spatial-data/environmental-response-management-application-erma
ERMA is an online mapping tool that integrates both static and real-time data in order to make informed decisions for environmental response, damage assessment and recovery/ restoration. ERMA enables a user to quickly and securely upload, analyze, export, and display spatial data in a Geographic Information System (GIS) map. It was developed by NOAA and the University of New Hampshire (link is external) with the U.S. Environmental Protection Agency, U.S. Coast Guard, and U.S. Department of the Interior.

**ERMA is designed to:**
- Visualize information relevant to spill preparedness and planning.
- Assist in coordinating emergency response efforts and situational awareness for human and natural disasters.
- Support the Natural Resource Damage Assessment process.
- Aid in ecological recovery and restoration efforts.
- Make large amounts of environmental data publicly accessible in a common operating picture to further the advancement of science and promote transparency and data sharing.

**NOAA Sea Grant. "University of Southern California (USC) Sea Grant publishes lessons learned from community engagement efforts."**
https://seagrant.noaa.gov/News/Article/ArtMID/1660/ArticleID/1675/USC-Sea-Grant-publishes-lessons-learned-from-community-engagement-efforts

**Full Report:**

Newton Mann, Alyssa; Grifman, Phyllis; and Finzi Hart, Juliette (2017) "The Stakes are Rising: Lessons on Engaging Coastal Communities on Climate Adaptation in Southern California," Cities and the Environment (CATE): Vol. 10: Iss. 2, Article 6. https://digitalcommons.lmu.edu/cate/vol10/iss2/6

**Seward Peninsula – Nulato Hills – Kotzebue Lowlands Rapid Ecoregional Assessment Report**

https://landscape.blm.gov/REA_General_Docs/SNK_REA_Final_Report.pdf.

M. Harkness, M. Reid, N. Fresco, S. Martin, H. Hamilton, S. Auer, S. Marchenko, J. Bow, I. Varley, P. Comer, P. Crist, and L. Kutner. Prepared for the U.S. Department of the Interior, Bureau of Land Management. October 2012.

**Statewide Threat Assessment: Identification of Threats from Erosion, Flooding, and Thawing Permafrost in Remote Alaska Communities**

https://02e.11d.myftpupload.com/wp-content/uploads/2019/11/Statewide-Threat-Assessment-Final-Report-20-November-2019.pdf

Report Prepared for the Denali Commission By University of Alaska Fairbanks Institute of Northern Engineering; U.S. Army Corps of Engineers Alaska District; U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory. November 2019.

**The H. John Heinz III Center for Science, Economics and the Environment. A Survey of Climate Change Adaptation Planning (2007)**

https://www.coolrooftoolkit.org/wp-content/uploads/2012/04/SurveyCCAdapatationPlanning.pdf

The report is divided into two sections: (i) adaptation planning guidebooks and frameworks, and (ii) adaptation planning efforts that are currently underway. This introductory survey report is designed to provide a "road map" to some of this information. It makes no claim to be comprehensive or to represent best practices on adaptation. Rather, as stated in the survey, "...*the goal in producing the survey is to help generate discussion and the sharing of ideas, efforts and lessons learned across the adaptation community.*"

**University of Alaska Fairbanks - Alaska Arctic Observatory & Knowledge Hub**

https://arctic-aok.org/about/

The Alaska Arctic Observatory and Knowledge Hub is a resource for northern Alaska coastal communities. AAOKH (pronounced A-OK) provides tools, resources and scientific information to share local expertise and observations of environmental change. Community-based observations focus on changes in sea ice, wildlife and coastal waters. Also a knowledge hub for sharing data, AAOKH has three main goals:

- Share and document community observations about changes to the seasonal cycle
- Make wildlife, ocean data and information from scientists accessible to communities
- Provide resources for education and outreach

**U.S. Army Corps of Engineers, Alaska District, Study Findings and Technical Report - Alaska Baseline Erosion Assessment (March 2009)**

https://www.denali.gov/wp-content/uploads/2018/10/Alaska-Baseline-Erosion-Assessment.pdf

The U.S. Army Corps of Engineers, Alaska District (Corps), conducted a Baseline Erosion Assessment (BEA) to coordinate, plan, and prioritize appropriate responses to erosion throughout Alaska. The study, begun in April 2005 and completed in March 2009, was specifically funded by the U.S. Congress. After conducting the study, the Corps prepared a technical report intended to help Federal, State, Tribal, and local stakeholders to develop strategies and plans for addressing erosion issues in Alaska.