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Remote Sensing for Asset Data Collection in Rural Alaska

FINAL REPORT



Prepared by:

Cole Smith, Elevate UAS

and

Mitchell McDonald, DOT&PF

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3132 Channel Drive

Juneau, AK 99801-7898

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Cole Smith and Mitchell McDonald

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Elevate UAS
6036 SW 18th Drive
Portland, OR 97239

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This report documents the evaluation of unmanned aerial systems (UAS) and advanced data analytics for asset data collection and condition assessment of gravel roads and runways in rural Alaska. The study addresses data gaps caused by logistical challenges, high costs, and limited accessibility associated with traditional inspection methods. UAS platforms equipped with high-resolution imagery and LiDAR were deployed to collect data along two road corridors on Kodiak Island and a gravel runway at Port Lions.

Machine learning and geospatial analysis techniques were developed to extract key roadway condition metrics, including ditch height, crown slope, drainage rills, pothole area, and washboard length. These metrics were used to establish a standardized, quantitative condition rating system applied at 0.1-mile segments. Results demonstrate that UAS-based data collection provides consistent, objective, and planning-level accurate assessments while reducing reliance on traditional field-based inspections.

The methodology enables scalable, repeatable, and cost-effective monitoring of rural infrastructure and supports inventory of secondary assets such as culverts, guardrails, and signage. Integration of UAS-derived data into asset management workflows improves maintenance prioritization, budgeting, and long-term infrastructure planning across remote regions.

14- KEYWORDS : Unmanned Aerial Systems (UAS), Remote Sensing, Gravel Road Condition Assessment, LiDAR, Machine Learning, Asset Management Systems, Rural Transportation Infrastructure, Pavement Surface Evaluation (PASER), Geospatial Data Analytics, Infrastructure Inspection, HFHWY00308

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3

		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353		oz
kg	kilograms	2.205		lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3

		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

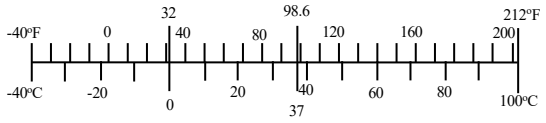


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The principal investigator and technical developer was Cole Smith, principal owner of Elevate UAS, LLC, in close coordination with Mitch McDonald, Regional Engineering Geologist Alaska DOT&PF Southcoast Region Materials, and with technical guidance on gravel road inspection by Drew Pavey, Statewide Pavement Manager DOT&PF Data Modernization & Innovation Office.

This work was guided by a commitment to support critical infrastructure in rural communities through the application of advanced remote sensing and computational technology. We recognize that local agencies often manage unpaved assets with limited resources, relying heavily on the professional judgment and institutional knowledge of their personnel.

Our goal with this project is to support those efforts by providing a more objective, spatial, and quantifiable framework for asset documentation, funding requests, and long-term budget forecasting. This work relied on a convergence of several scientific disciplines, building upon fundamental principles established by those before us. We are grateful to the researchers and practitioners whose dedication and past contributions have provided the foundation for these technological advancements.

“If I have seen further, it is by standing on the shoulders of Giants”

- Sir Isaac Newton

1.0 Project Background

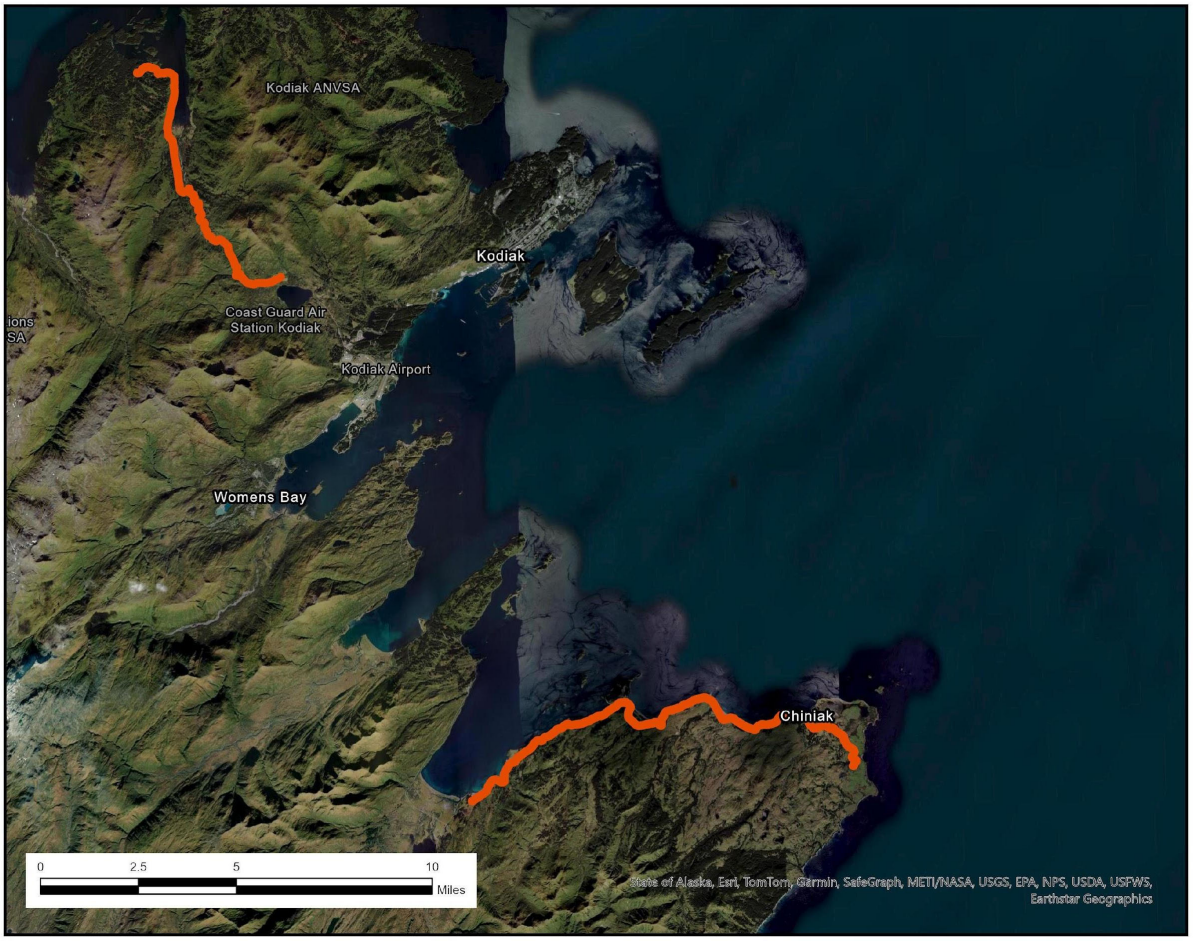
Alaska DOT&PF manages hundreds of facilities and critical infrastructure assets across the nation's largest state. In the remote, rural regions of Alaska the majority of roads and airports are constructed with gravel surfacing materials which have a disproportionately high cost when local aggregate sources and processing equipment are not available. Due to the numerous logistical challenges, high travel costs, and inclement weather, site inspections, asset data collection, and condition assessments for gravel roads are difficult to perform at regular intervals. This difficulty has created substantial data gaps for gravel roads in rural communities. In the less remote parts of the state annual assessments of the pavement condition are conducted using vehicle mounted equipment as part of the Pavement Management System (PMS). This same vehicle mounted equipment cannot be reasonably mobilized to rural Alaska and is not ideally suited for use on gravel surfaces.

To address the data gap and use of less effective vehicle mounted equipment, Unoccupied Aerial System (UAS) platforms can be outfitted with advanced payloads to obtain high resolution imagery and LiDAR, capable of collecting useful data for the inventory of gravel roads. When this data is combined with advanced data processing techniques, including machine learning algorithms, it can be used to perform condition assessments based on criteria more suited to gravel surfacing than what is used for paved surfaces. UAS platforms are easier to mobilize than traditional vehicle mounted systems and can provide a cost-effective way to provide more regular inspection of gravel roads. If data can be obtained via UAS it is possible that a small team of people can make a single site visit and provide remote sensing data that can be used in multiple ways, by multiple user groups, and during all phases of planning, project design, and maintenance. This would provide cost savings in travel expenses, planning and budgeting. Additionally, by providing higher quality data than is traditionally available, project scoping and delivery can be improved with lower design costs. The same UAS platforms might also be demonstrated to be useful for inspection of airports, material sites, and rock or soil slopes.

The research team has evaluated the optimal UAS platform, payload, data collection methods, logistical feasibility, and data analysis methods using modified criteria from the PASER manual. Results from this work are demonstrated to be sufficient for planning level decision support for the maintenance, design, and construction of gravel roads. This project also evaluated which secondary assets can be opportunistically inventoried at the same time (e.g. signs, culverts, and guardrail) and if the imagery and LiDAR can be upcycled for use in project design and maintenance.

This report covers the initial testing of two gravel road corridors located on Kodiak Island shown in Figure 1. The desired outcome of this demonstration is to establish safe, cost effective and reliable inspection and data management for critical rural assets utilizing remote sensing and advanced data processing technologies.

Figure 1: Project locations on Kodiak Island are shown as orange lines. The Anton Larsen Bay Road is north (top of page) and Chiniak Highway is south (bottom of page).



2.0 Summary of Tasks

Task 1: Collaboration and Stakeholder Identification

The purpose of this task was to identify all potential user groups across DOT&PF, identify all assets that can be reasonably inventoried and assessed, and determine a suitable field area to serve as case study locations.

Task 2: UAS Selection and Payload Specification

Elevate conducted preliminary test flights on an easily accessible gravel road near Juneau. The purpose was to determine optimal camera selection and settings to collect appropriate image resolution and to identify optimal flight parameters to capture pre-determined assets. Results from this preliminary testing determined which UAS, payloads, and the specific flight parameters that would be used in the field area identified in Task 1.

Task 3: Demonstration and Analytics

Two gravel roads on Kodiak Island were identified to serve as the case study locations. Elevate traveled to Kodiak for 8 days to collect data along Anton Larsen Bay Road from mile post 2.9 to 11.7 and along Chiniak Highway from mile post 20.0 to 33.4. Once the data was collected Elevate worked with DOT&PF to develop criteria to be used to assess the condition of gravel roads and then developed machine learning methods to perform the analysis and provide condition rating. Machine learning was also used to develop automated extraction of secondary assets from the same data that included signs, culverts, and guardrail.

Task 4: Workflow Integration and Deliverables

This task is to develop best practices to transfer the data analyzed in Task 3 in an optimal file format and deliverable for all identified user groups. Final decisions were made to identify which assets could be reasonably and reliably extracted from the collected data. The goal was to develop standards for repeatable data collection to allow for enhanced monitoring of assets in rural communities.

Task 5: Reporting

The final report will present the findings of the research, make recommendations for using the processes developed during the study to implement an Unpaved Asset Management System (uPMS), and provide specifications for data resolution (Table 3), so data collection can be contracted out in a fashion similar to the PMS.

3.0 Collaboration and Stakeholder Identification

Project development started with weekly meetings between the Elevate Team and Mitch McDonald, Southcoast Regional Engineering Geologist and Project Champion, to better refine the research scope. From coordination with the Statewide Pavement Engineer, Drew Pavey, the Pavement Surface Evaluation and Rating (PASER) Manual developed by Wisconsin Transportation Information Center and the University of Wisconsin-Madison (1987, 1989, & 2002) was identified as the reference that will be used to determine the preliminary condition metrics. It was also determined that any uPMS would best be used if it were tied to the Statewide Linear Referencing System (LRS) so it could be integrated readily with other existing statewide Transportation Asset Management (TAM) Systems. Stakeholder groups within DOT&PF, which could benefit directly or indirectly from this work, were identified and are listed in Table 1.

Table 1: Summary of DOT&PF User Groups

DOT&PF Group	Description of Use
Statewide Pavement Engineer	One scenario could include the Statewide Pavement Engineer managing a program similar to the PMS for gravel surfaced infrastructure, the uPMS
Maintenance & Operations	Provide regular inspections of gravel roads to identify and prioritize funds for annual resurfacing projects.
Reconnaissance Engineer	Upcycle the imagery for project development and use data to improve project scoping for preservation or rehabilitation

	projects including any additional assets such as guardrail or signs.
Planning	The uPMS as described herein would provide Planning with basic statistics such as miles of gravel road inspected and the associated condition ratings.
Geology & Geotechnical	The imagery and LiDAR could be reused for basemaps, to map distress areas and slope failures
Hydrology and Hydraulic Engineer	LiDAR could be used to develop hydraulic models of the roadside ditches and expand culvert inventories
Environmental	Imagery could be used for basemaps, wetland delineation, and invasive species mapping
Survey	Imagery provides a good planning tool for design topo surveys
Right Of Way	Imagery could be used to identify encroachments that need to be cleared
Traffic Engineers	Expand inventories of signs and guardrail in rural areas where significant data gaps exist
Civil Design Engineers	Imagery could provide adequate design planning tool and preliminary figures used for project scoping confirmation

4.0 UAS Selection and Payload Specification

Preliminary testing was conducted on a City & Borough of Juneau owned gravel road being extended to the west side of Douglas Island in Juneau, Alaska. This site was selected because it provided easy access to conduct preliminary testing of airframes, sensors, and flight planning parameters used for the project sites on Kodiak.

The UAS chosen for this project was a DJI M300 RTK aircraft. The UAS image data was captured with a DJI Zenmuse P1 45MP 34×19 mm sensor, using a 24mm lens. UAS LiDAR was collected using a GeoCue TrueVue 535, which relies on a Hesai M2X scanner and Applanix APX-15 position orientation system. In general, LiDAR and imagery field data acquisitions followed best industry practices and procedures recommended by the manufacturers and the FAA. *Note that this data was collected prior to the full implementation of the American Security Drone Act (part of the National Defense Authorization Act) that bans the procurement or use by the federal government UAS that originate in foreign countries that use federal funding. All flights were conducted to comply with federal (FAA Part 107) and state regulations.*

Flight parameters were evaluated based on the resolution of the resulting processed data and efficient data acquisition. The selected flight parameters are described in the table below.

Table 2: Summary of Recommended Flight Parameters

Data Product	Altitude (m)	Speed (m/s)	Sidelap (%)
Imagery	55	10	80
LiDAR	55	5	60

Resolution of the data products dictates the success of the analytical results. The target resolution for both imagery and LiDAR is summarized in the data table below.

Table 3: Recommended Resolution and Point Density of Orthomosaic and LiDAR Deliverables

Data Product	Resolution / Point Density (ft | m)
Orthomosaic	0.024 ft/pixel | 0.0073 m/pixel
Photo DEM	0.1 ft/cell | 0.03 m/cell
LiDAR Point Cloud	80/ft²-140/ft² | 861/m²-1,507/m²
LiDAR DEM	0.5 ft/cell | 0.15 m/cell

5.0 Demonstration and Analytics

5.1 Data Acquisition

The initial data collection took place between September 6, 2023, and September 13, 2023. The first area collected was an 8.9-mile stretch of Anton Larsen Bay Road (ALB), located in the northern central portion of Kodiak Island. The second was a 13.4-mile portion of Chiniak Highway located in the southeastern portion of the Island (Figure 1). Both selected roads are in the statewide Linear Reference System (LRS), unpaved gravel and connect to a paved road. These roads were selected because they represented variability in topography, vegetation, and current condition, allowing for a more diverse dataset to build and train a model. LiDAR and imagery were collected during clear and calm weather conditions. The data was initially inspected for completeness and then stored in an external hard drive under the documented flight and date. Specific details on the data captured are described in the data table below.

Port Lions is a small community west of Anton Larsen Bay and is serviced by a gravel runway. The project team discussed the feasibility of conducting a gravel condition assessment analysis on a gravel runway, as this infrastructure is critical to rural communities and lacks a consistent and objective methodology for routine inspections. Adding the Port Lions runway to the data collection effort would also demonstrate the ability to conduct this work in remote regions of Alaska as all necessary equipment could be loaded onto a charter plane and transported to the project site.

Table 4: Data Collection Summary

Location	Images #	Imagery File Size (GB)	LiDAR File Size (GB)
Chiniak	8,377	175	191
Anton Larsen Bay	6,112	131	130
Port Lions Airstrip	7,049	146	35

5.2 Metrics for the Condition Rating System

To determine which features would be most beneficial for establishing a rating system for unpaved roads the PASER Manual was used for guidance. The major condition metrics used to determine a performance rating in the PASER Manual are crown, drainage, gravel layer, surface deformation, and surface defects. The table below summarizes these metrics, their definitions in the PASER Manual, a Confidence of high/medium/low for how successful the UAS data collection and analytics were expected to perform, and Data Priority of primary or secondary in its use as a performance metric.

Table 5: Summary of Gravel Road Metrics from the PASER Manual. Confidence was determined by the Elevate team based on their understanding of whether the acquired data could provide enough context to measure that criteria. Data Priority was determined by DOT&PF to indicate the priority of these criteria.

Criteria	PASER Definition	Confidence	Data Priority
Crown	Unrestricted slope of roadway from center across shoulders to the ditches	High	Primary
Drainage	Ability of roadside ditches and under-road culverts to carry water away from the road	Medium	Primary
Gravel Layer	Adequate thickness and quality of gravel to carry traffic loads	Medium to low	Secondary
Surface Deformation	Washboards, potholes and ruts	High	Primary
Surface Defects	Dust and loose aggregate	Medium	Secondary

After collection and initial review of the data, the PASER criteria were reviewed in detail to determine the feasibility of the remotely sensed data being used for evaluating each of the selected criteria. Initial analysis included an evaluation and inspection of data quality, characterization of the features defined by PASER criteria, then review of whether those features could be extracted autonomously through machine learning. It became clear some features could be defined and extracted, as there were sufficient examples to be able to classify and train a

model, while other features were less frequent or more difficult to identify consistently through all data sources. The final criteria and their definitions are presented below in Table 6.

Table 6: Final Criteria to be Used for Gravel Road Condition Assessment

Characteristic	Definition
Ditch Height	Long, narrow, open channel dug alongside a road, primarily used to drain water and prevent it from accumulating on the road surface or surrounding areas.
Crown Slope	Slight, gradual slope or incline of the road surface from the center to the edges, designed to facilitate drainage and prevent water accumulation.
Drainage Rills	Rills, which are small channels eroded by water, indicate poor drainage and should be addressed.
Pothole	Depression or hole in the road surface, similar to those found on asphalt roads. It's a form of surface distress where the gravel has been eroded or displaced, creating a hollow.
Washboard	Also known as corrugation, refers to the formation of periodic, transverse ripples on gravel and dirt roads. These ripples resemble the grooves on a washboard.

Several physical assets that were of interest to DOT&PF included road signs, guardrail, and culverts. These were relatively straight forward to extract from the processed data and are categorized into a secondary asset group described in Table 7. These features were imported into the geodatabase to document additional information about their quantities. At the time of this reporting there is insufficient information to determine the quality or condition of these features. Culvert diameter was estimated in inches in an attempt to extract additional information for these features. These features were inventoried to support DOT&PF's asset management program, but they do not factor directly into the road condition ratings. It is possible for them to be incorporated into the rating system through future development of this methodology. For example, guardrail metrics (number of posts vs linear distance), or number of signs approaching a turn, verification of culvert diameter, etc.

Table 7: Secondary Asset Groups were identified and captured to generate a digital inventory and extract additional information about them.

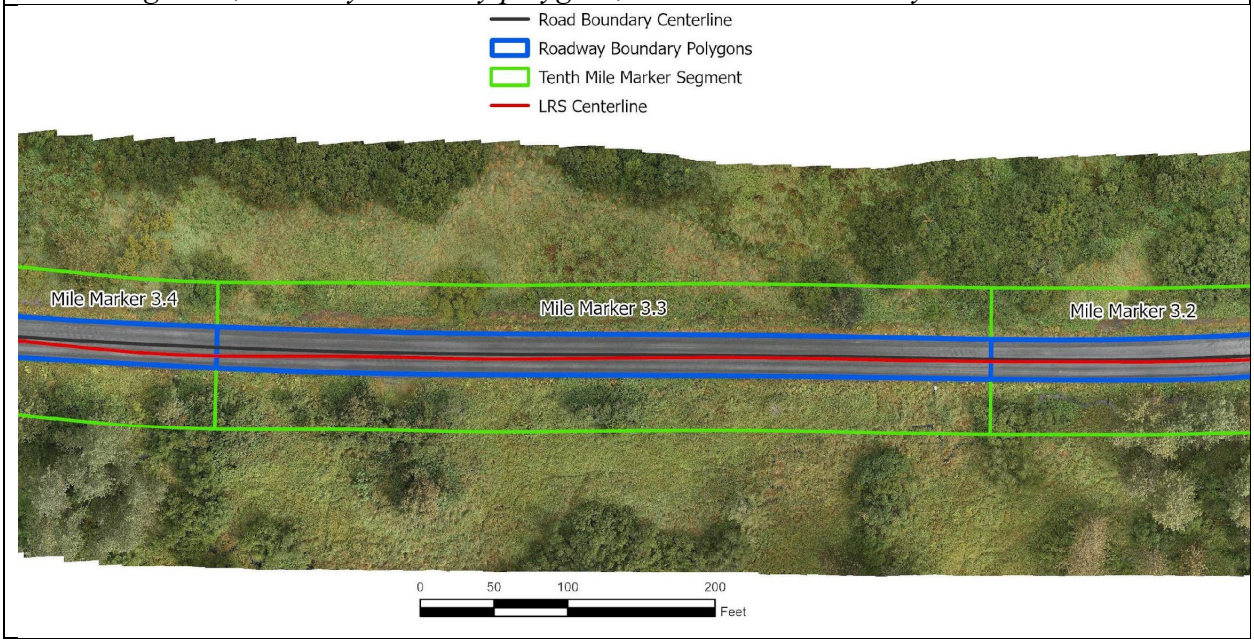
Asset Group	Definition
Culverts	A structure that allows water to flow under a road or other obstruction
Guardrails	Roadside safety barrier designed to protect vehicles and occupants from hazards like obstacles or steep slopes when a vehicle leaves the intended roadway.
Road Signs	Structures erected along roadways to provide information and guidance to road users.

5.3 Data Classification and Segmentation

The ALB location was used as a training model for the development of the analytical methods, as it represented a better candidate for standard gravel road conditions, was more recently repaired, and has less vegetation issues than the Chiniak site. At the request of DOT&PF the analysis was designed to segment each road into tenth-mile (0.1) segments that correspond to the existing DOT&PF LRS.

Centerlines extracted from the LRS data for ALB and Chiniak Highway were queried from the public DOT&PF Roads online geodatabase and imported into the project geodatabase. The LRS mile marker data was used to create 0.1-mile polygon segments with a 100-foot buffer to summarize the road condition data. LiDAR data was classified to categorize the ground surface, guardrails, road signs, and vegetation. A polygon representing the outer boundary of the gravel roadway for each AOI was generated from the classified LiDAR (class 11 - Road) in .dgn and .dwg format. Irregularities were manually edited, and a centerline was generated from the edited polygon. This centerline is more representative of the "geometric centerline" of the gravel road surface, which regularly varies and diverges from the LRS centerline feature. The area of gravel in the roadway was calculated from the LiDAR road classification by summarizing the roadway boundary polygon area for each 0.1-mile segment (Figure 2).

Figure 2: Example of the high resolution orthomosaic overlaid with the LRS centerline, mile marker segments, roadway boundary polygons, and the road boundary centerline.



Road Rating segment polygons representing 0.1-mile intervals were used to summarize the road condition, with each segment bearing an identifying mile marker value derived from the LRS centerline dataset.

The five key features that could be extracted from the processed data are described in Table 8. The metrics for these five features; Slope, Ditch Height, Rill Length, Pothole Area, and

Washboard Length, were then rated on a scale of 0 to 3, with 0 representing the ideal condition and 3 representing the worst variable condition. See the rating matrix in Table 9 for how these rates were calculated. The five features that were rated were summed to arrive at the road condition, or Road Rate value for each segment, with a maximum value of 15 (5 x 3). Each section is given a rating based on the aggregate of the variable condition.

Additional information that does not easily fit into the evaluation of the gravel road condition rating was captured and considered valuable for certain DOT&PF user groups. The ground classified LiDAR off the road surface is useful for understanding adjacent terrain drainage patterns and the evaluation of culvert placement. At the time of this reporting, this type of data will be delivered to DOT&PF, but not incorporated into the overall condition assessment of the gravel roads.

5.4 Condition Rating System Development

While the PASER classification was used as an example of unpaved road condition ratings, DOT&PF determined that a unique classification would be more beneficial to their stakeholders. Elevate worked with DOT&PF to develop a standardized, quantifiable, and objective rating system for five key features, which have the strongest influence on the overall condition of the gravel road system. These criteria are intended to be applied through data analytics and not developed for visual inspections. The table below is a summary of the proposed rating system.

Table 8: Proposed Alaska DOT&PF Road Rating System

		Defined Metrics and Point Rating System			
Feature	**Description**	**0**	**1**	**2**	**3**
Ditch Height	Bottom of ditch (i.e. lowest elevation) to top of crown. minimum and maximum values stored for each segment.	>=36"	<36"-24"	<24"-12"	<12"
Crown Slope Range	Top of crown to edge of shoulder, minimum and maximum slope values stored for each segment.	2-4%			all other measures
Sum Drainage "Rills" Length	Length of rills in feet => level 1 within road area and drainage basin size (see basin size table)	<18.75’	18.75’ - 250’	250’ - 500’	>500’
Pothole Area	Area in square feet of potholes of at least 1/2" depth	<25 ft²	25 – 50 ft²	50 - 100 ft²	>100 ft²
Washboard Length	Classification by length relative to car wheel base	<25'		25’ - 50'	>50'

Note that a lower point value for each feature corresponds to a lower point rating and is categorized to have a better road condition.

The road rating for each 0.1-mile segment is the sum of the Ditch, Slope, Rill, Pothole and Washboard ratings shown in Table 8, with a maximum value of 15. Road rating values from 0-15 were then summarized to a Good, Fair, and Poor system shown in Table 9.

Table 9: Proposed Road Condition Ratings

Segment Road Rating	
Condition	**Point Values**
Good	0 - 4 Points
Fair	5 - 9 Points
Poor	10- 15 Points

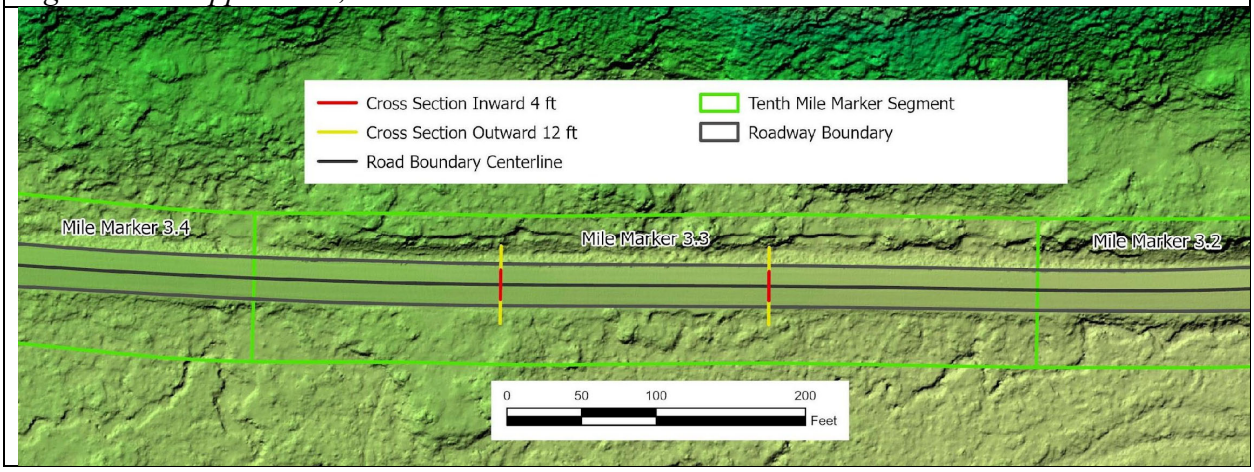
6.0 Explanations of Features Used for Condition Ratings

Features identified by DOT that were able to be incorporated into the modeling analysis are described in this section. These are features listed in Table 8 and are used to summarize the overall segment road rating.

6.1 Ditch Height

Two cross-section lines were created at the same 176-foot spacing from the beginning and end of each 0.1-mile road segment. The road boundary polygon was buffered outward 12 feet, at the direction of the DOT&PF, to detect the minimum ditch elevation. The cross-section lines were again split into two segments at the road boundary centerline, and minimum ditch elevation values were extracted from a DEM derived from ground-classified LiDAR with 0.5 ft resolution for each of the 4 cross section segments (Figure 3). Minimum ditch elevation (within the 12-foot outward road buffer) was subtracted from crown height elevation (within the inward 4-foot road buffer) to calculate ditch height (Figure 4).

Figure 3: Example in map view of the cross-section lines and distribution within a 0.1-mile segment. See Appendix B, Exhibit B-5 – B-10.

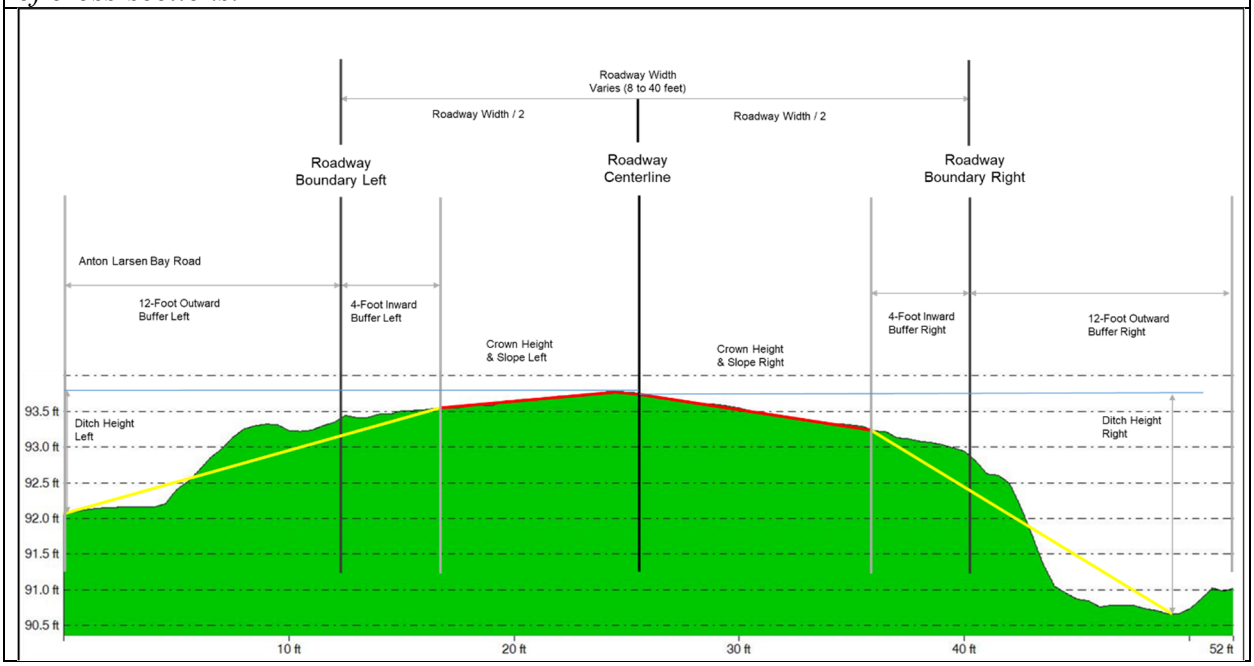


6.2 Slope, Crown Height, and Roadway Width Assessments

Two cross-section lines were created at a spacing of 176 feet from the beginning and end of each 0.1-mile road segment. The road boundary polygon was buffered inward four feet for the calculation of slope and crown height, to exclude the uneven shoulder area and encroaching vegetation. This focused the analysis to the traveled, middle surface area, of the roadway. The cross-section lines were split into two segments at the road boundary centerline to separately calculate slope and crown height on left and right sides of the road (Figure 3). Maximum and minimum elevation were extracted from the DEM for each of the four cross section segments. To calculate Crown Height, the minimum elevation was subtracted from maximum elevation from the cross sections clipped to the four-foot inward road boundary buffer. Slope was calculated using the following formula: Slope = (Crown Height/Cross Section Length) x 100.

Maximum and minimum roadway width values were calculated by clipping the cross-sections to the roadway boundary (Figure 4).

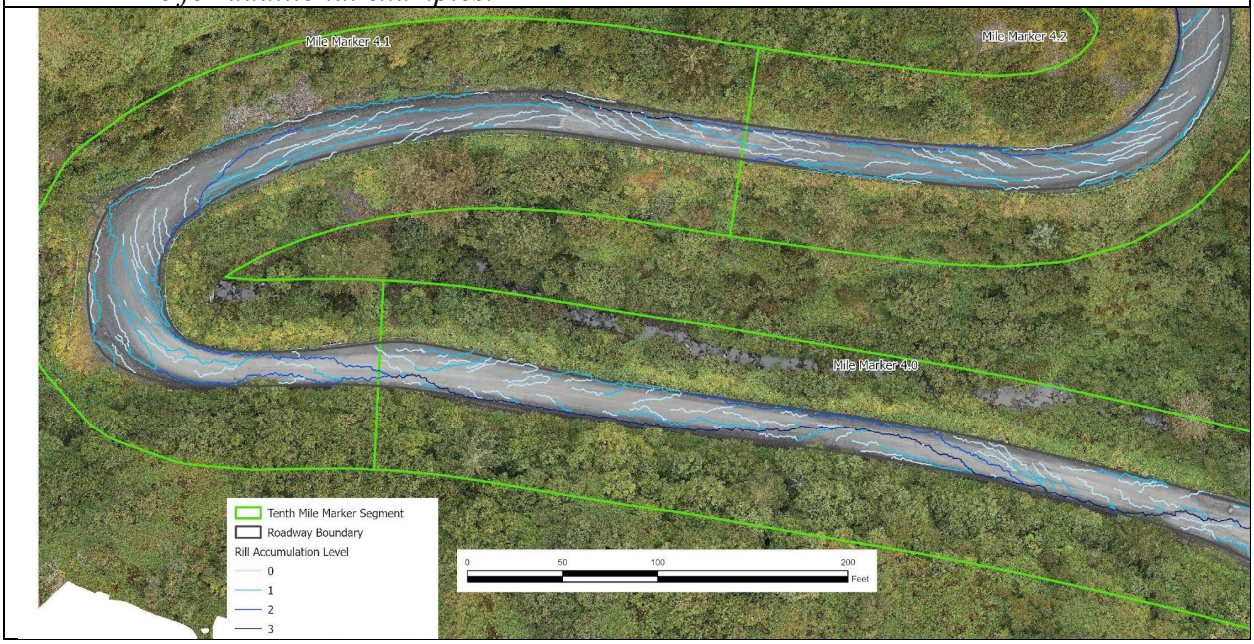
Figure 4: Example cross-section with descriptions of how the analysis for Slope, Crown Height, and Roadway Width are calculated. See Appendix B, Exhibit B-7 – B-10 for example of cross-sections.



6.3 Roadway Hydrology/Rills

The Photo DEM, with 0.1 ft resolution, was clipped to the roadway boundary polygon. Industry standard hydrology analysis steps were performed on the clipped DEM. Polylines were generated and represent rills or channels of modeled surface flow (and erosion) during rainfall events across the roadway surface (Figure 5). Rills with accumulation level 0 are filtered from the roadway analysis but are useful for visualizing road surface slope and the direction of surface water. Rills within four feet inward from the roadway boundary were also filtered out of the roadway analysis to avoid including the shoulder area, where flow accumulation is less likely to affect the driving surface. The length of the remaining level 1-3 rills within the roadway are summed per segment and given a point value based on the pre-defined metrics in Table 8.

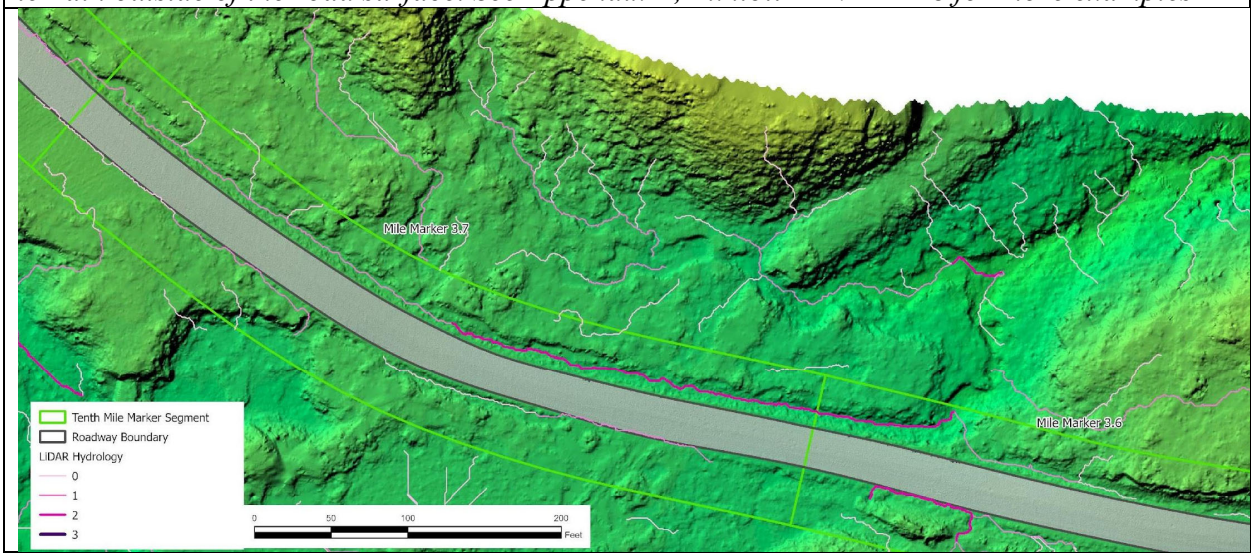
Figure 5: Orthomosaic overlaid with hydrology rills on road surface. See Appendix B, Exhibit B-11 – B-16 for additional examples.



6.4 LiDAR hydrology/rills

The LiDAR-derived DEM covering the full extent of data collection area, was used with industry standard hydrology analysis, similar to the roadway hydrology methods described above. Polylines representing engineered ditches, streams and channels of surface flow and erosion, adjacent to the road were generated (Figure 6). It should be noted that culverts were not hydrologically modeled, so the roadbed stands as a "hydrological barrier" within the model. This causes errors and artifacts in the output that were not addressed. The LiDAR hydrology was not used in the roadway analysis and is provided for visualization of drainage patterns along the adjacent terrain.

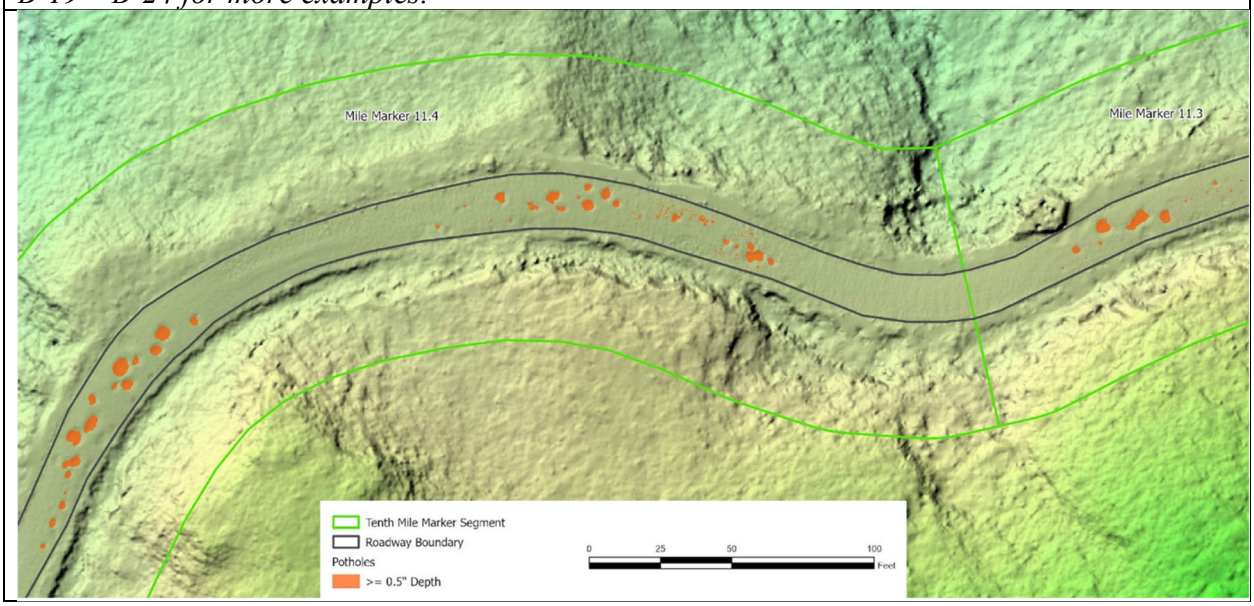
Figure 6: Hydrology analysis from the LiDAR derived DEM was conducted on the adjacent terrain outside of the road surface. See Appendix B, Exhibit B-17 – B-18 for more examples



6.5 Potholes

The Photo DEM, with 0.1 ft resolution, was used for Pothole detection. Industry standard methods for raster analysis were used to generate a new raster where pixel values represent potholes with depths in feet. A value of 0.04 ft (approximately 0.5 inch) was chosen as the minimum depth for pothole detection and the data was reclassified to highlight these features (Figure 7). Potholes within four (4) feet of the roadway boundary were considered to be in the shoulder and therefore excluded from the pothole calculation.

Figure 7: Hybrid DEM used for pothole analysis. Examples of potholes ≥ 0.5" are highlighted in orange and included in the pothole area calculation. See Appendix B, Exhibit B-19 – B-24 for more examples.



With this method, the pothole depth values are less than might be measured on the ground or with other DEM-smoothing interpolation methods. Depressions remained in the filled DEM at pothole locations, resulting in depth values generally in the 0.04 to 0.25 ft range, whereas potholes on the ground are likely to be greater than these modeled depths. It is assumed that these values can serve as a minimum fill volume to bring the pothole up to within 0.5" of road surface grade. Other methods were attempted to calculate a more representative value but were not successful. The score for this feature was based on the area of each section covered by potholes. Additional analysis can be conducted to compute the minimum fill volume to bring the potholes up to grade, however, this was not conducted by time of this reporting.

6.6 Washboard

Detection of washboard was attempted with the LiDAR point cloud and DEM elevation data, but the vertical variation was found to be too subtle for the methods\data used. Image classification was carried out to automate detection of apparent washboard patterns in the RGB orthomosaic data. Unfortunately, the classification was unsuccessful with few areas of washboard detected. Automated detection was deemed inefficient at the time of reporting and manual detection of washboard data was conducted by viewing the RGB orthomosaic and Photo DEM, then digitizing lines representing the location and length of washboard running parallel to centerline (Figure 8). Manual digitization took approximately 2 minutes per mile.

Figure 8: High resolution orthomosaic showing the washboard pattern and the manually digitized line to quantify the approximate length of washboarding within the road segment. See Appendix B, Exhibit B-25 – B-29 for examples of washboard on the road surfaces.

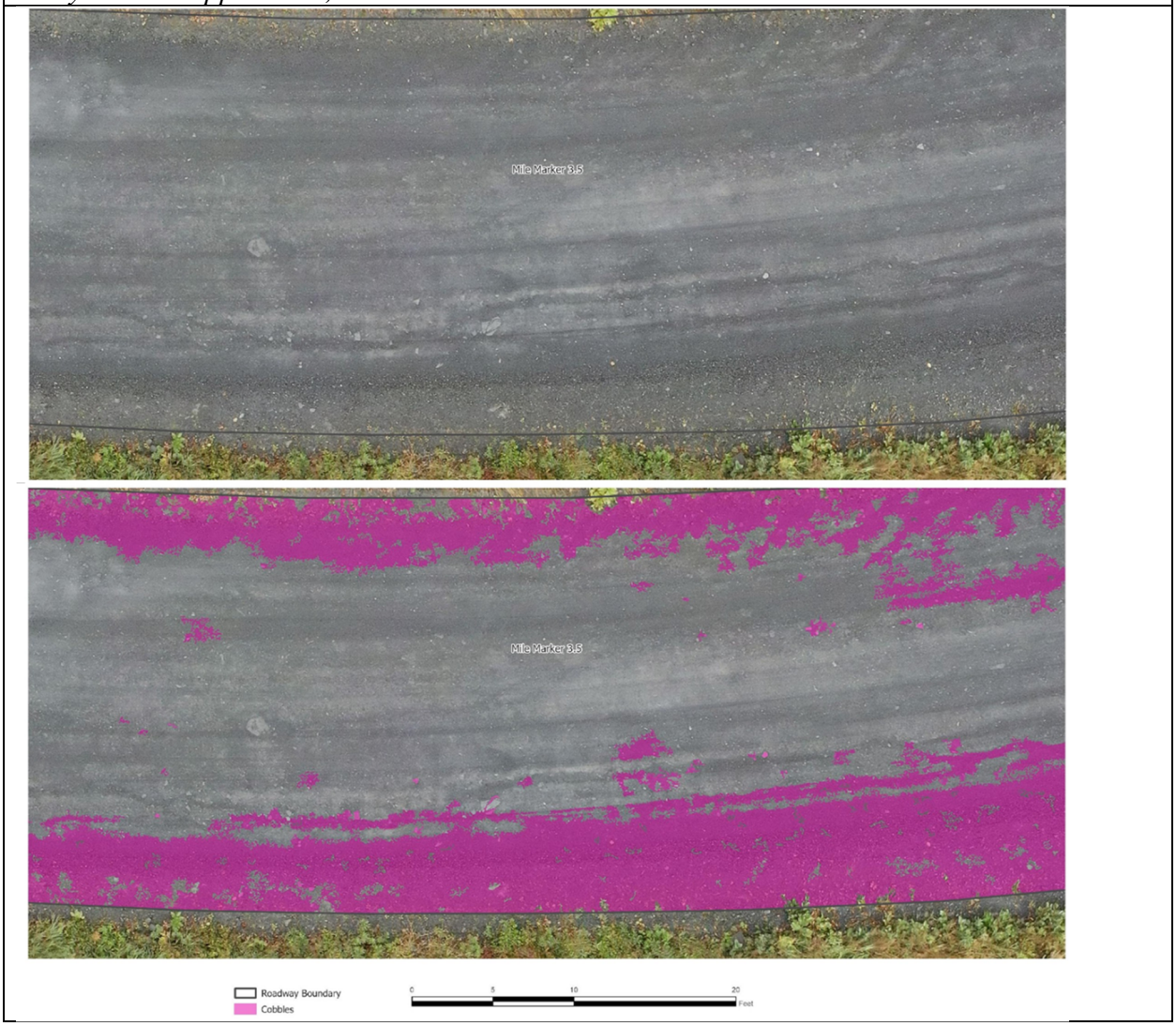


While manual visual identification of the washboard features was ultimately conducted for this project, the process was relatively simple and efficient. The benefit of this method is that it can be used to provide training data for automated extraction in the future. Elevate is exploring additional analysis techniques to refine and automate this process. This automation, planned for release in version 2 of the product, will allow for increased standardization and further reduce manual efforts.

6.7 Cobbles

The high resolution RGB orthomosaic (0.024 ft/pixel) was clipped to the road boundary and classified. The model was trained to detect aggregate material in the roadway with a visible dimension greater than 2 inches (0.167 ft) (cobbles), and aggregate with a dimension less than 2 inches (gravel). The analysis was carried out on a half-mile test portion of ALB. Areas of cobbles were detected with an estimated 60-70 % success rate using classification methods in the test area, however, this analysis was not included in the road rating (Figure 9).

Figure 9: Example of the orthomosaic where cobbles are visible and the misclassified cobble analysis. See Appendix B, Exhibit B-30 – B-31.



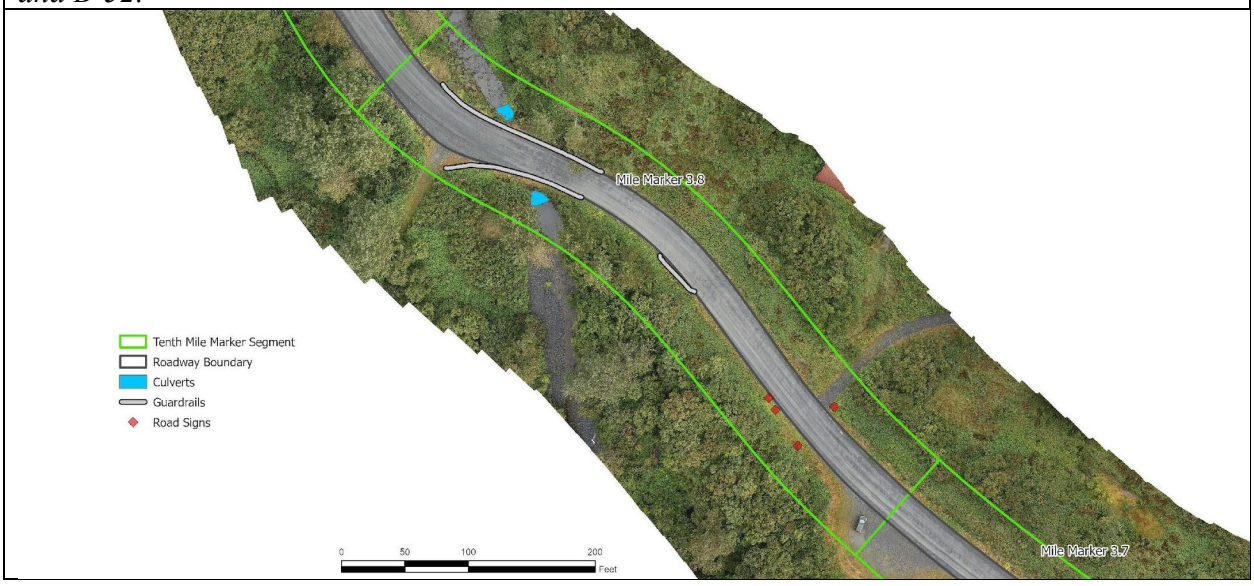
Lighting conditions (shadows) and overhanging vegetation caused false positive detection. Compared to the other analysis steps described above, this step took considerably more human and computational time. The method used in the initial ALB test area did not scale to analyzing the larger files that made up the complete corridors. Lighting conditions varied substantially more in the Chiniak orthomosaic with areas of shadow and bright sunlight. This reduces the

detection rate of cobbles dramatically since the training data from ALB were used for classification and would require retraining. Considering the relatively high effort, at the time of reporting, the cobbles analysis was not completed for either AOI, however substantial progress toward creating a workflow that may successfully automate and summarize the area of cobbles per road segment was made.

7.0 Secondary Asset Groups

A key component of the study was to determine which, if any additional asset data could be extracted from the orthomosaic and LiDAR collected for the gravel road condition assessment. The road signs, guardrails and culverts, were physical assets that were digitized to add to the DOT&PF gravel road inventory database. Additional features that could readily be extracted from the processed data that was of interest to DOT&PF also included Road Width, Roadway Area, and LiDAR hydrology analysis adjacent to the road. This data was included in the final geodatabase delivered to DOT&PF but not used in calculating the road rating.

Figure 10: Example of the secondary asset group detected through this analysis. Examples of this analysis of these features can be viewed in Appendix B, Exhibit B-32 – B-35, and B-51 and B-52.

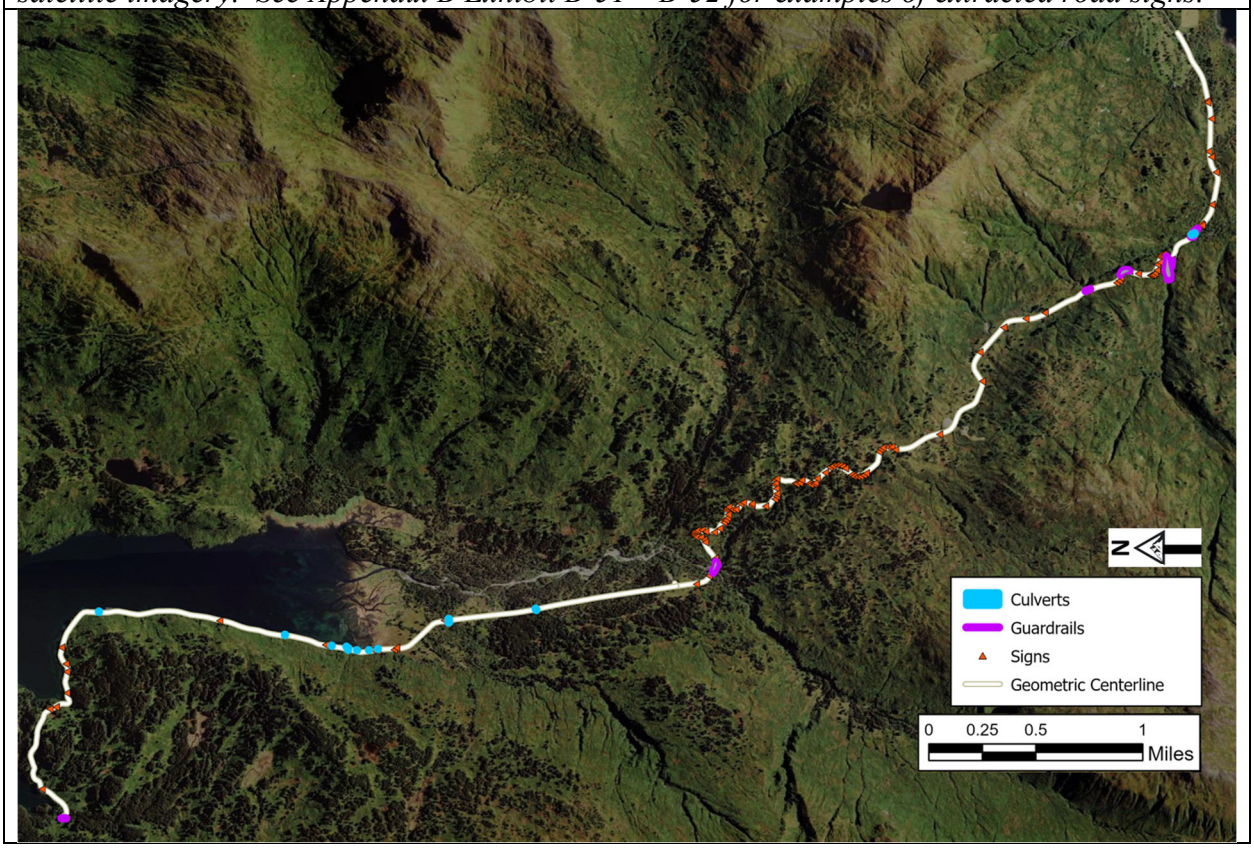


7.1 Road Signs

The road signs layer appears to contain false positive detections that are likely other objects, which extend above the surrounding vegetation. It is difficult to verify many of the detected signs in the imagery because they are perpendicular to the imaging orientation and sometimes obscured by vegetation. Signs may be more verifiable in oblique or offset imagery or by conducting data collection at different points in the year when interference from vegetation will be less. Further, as data collections are conducted on an annual, or regular basis, comparisons of the extracted signs will validate the location data or flag it as unvalidated. If a sign is identified in multiple datasets, there will be higher confidence in its presence and location. Initial analysis extracted a total of 139 signs on ALB and 267 signs on Chiniak (figure 11). At this time, the

model is unable to determine the type of sign, but with the collection of more oblique imagery, it is possible that sign type could be determined in future versions.

Figure 11: Secondary Asset Groups extracted from ALB are shown overlaying low resolution satellite imagery. See Appendix B Exhibit B-51 – B-52 for examples of extracted road signs.



7.2 Guardrail

Guardrails were classified in the LiDAR classification process; however, some lengths of guardrail are visible in the imagery and were not detected in automated LiDAR classification (see Appendix B, Exhibit B-34). This appears to be a relatively small percentage of overall guardrail length and isolated to areas where there was overhanging vegetation. Analysis of the extracted guardrail captured a total of 11 sections of guardrail, measuring 2,257 feet on ALB and 56 sections of guardrail, measuring 22,005 feet on Chiniak (Figure 12).

Figure 12: *Secondary Asset Groups* extracted for Chiniak are shown overlaying low resolution satellite imagery.



7.3 Culverts

Culverts had several false positive detections, mostly from dead trees or rocks, and culverts that were not detected in LiDAR classification due to vegetation cover or other factors (Figure 13). The culvert detection rate was approximately 1 to 1.5 per mile. At this time human confirmation of false positive culverts is recommended. Further detection of culverts by automated means may be aided by visualizing the LiDAR hydrology layer and high-resolution imagery or LiDAR DEM. The total number of culverts detected on ALB was 17 and the total on Chiniak was 12. Additional analysis of culvert diameter can only be done on clearly visible culverts.

Figure 13: Examples of misclassification of culverts detected in the imagery.



7.4 Additional Features

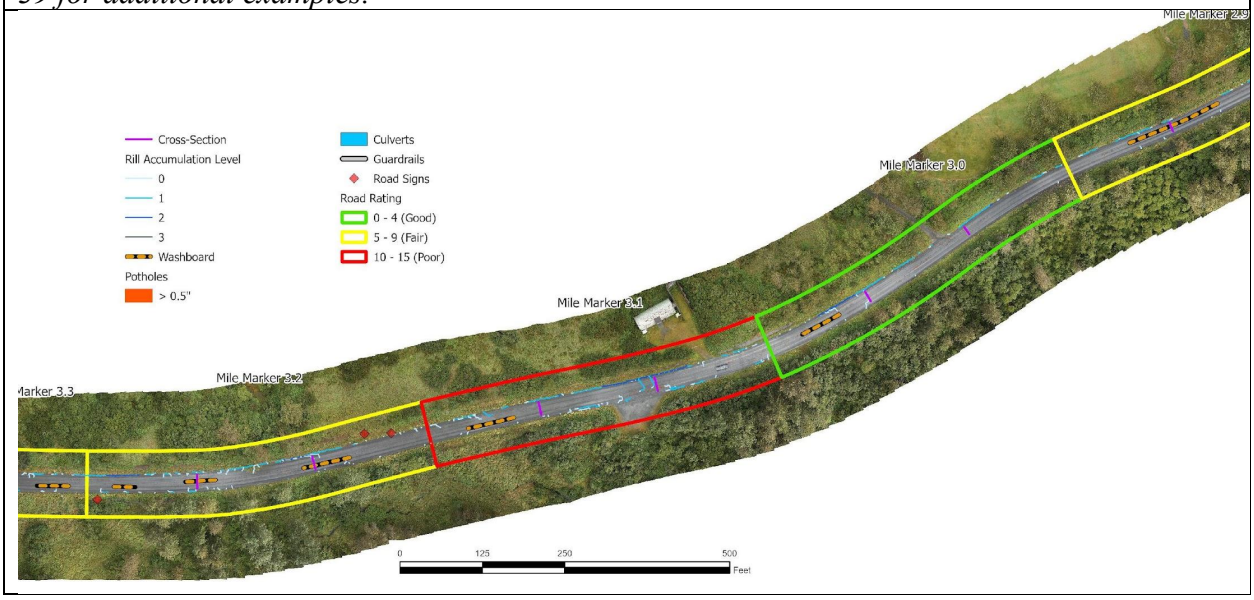
Additional features that were readily extracted from the data with no clear metrics in either the PASER Manual or by DOT&PF included Road Width, Roadway Area, and LiDAR hydrology analysis adjacent to the road. This information was determined to be potentially useful information for at least one or more DOT&PF user groups and was included in the delivered geodatabase. Road Width and Roadway Area were calculated within each 0.1-mile segment polygon and included within the attribute table for each respective polygon. The LiDAR hydrology layer was included as a separate polyline layer to illustrate the drainage patterns adjacent to the road corridor.

8.0 Findings

In general, site conditions on arrival were assessed to be acceptable to conduct UAS operations and data collection. All of the locations identified in Task 1 were able to be imaged with sufficient detail for model development and project analysis.

The rating system outlined in Table 8 is sufficient to summarize the gravel road conditions (Figure 14). At a minimum, this work provides an overall standardized, automated, and quantifiable gravel road condition assessment, with a detailed geospatial and visual context. The secondary asset group and additional features could lead to deeper understanding and better management of this infrastructure once DOT&PF incorporates this data into their asset management system workflow.

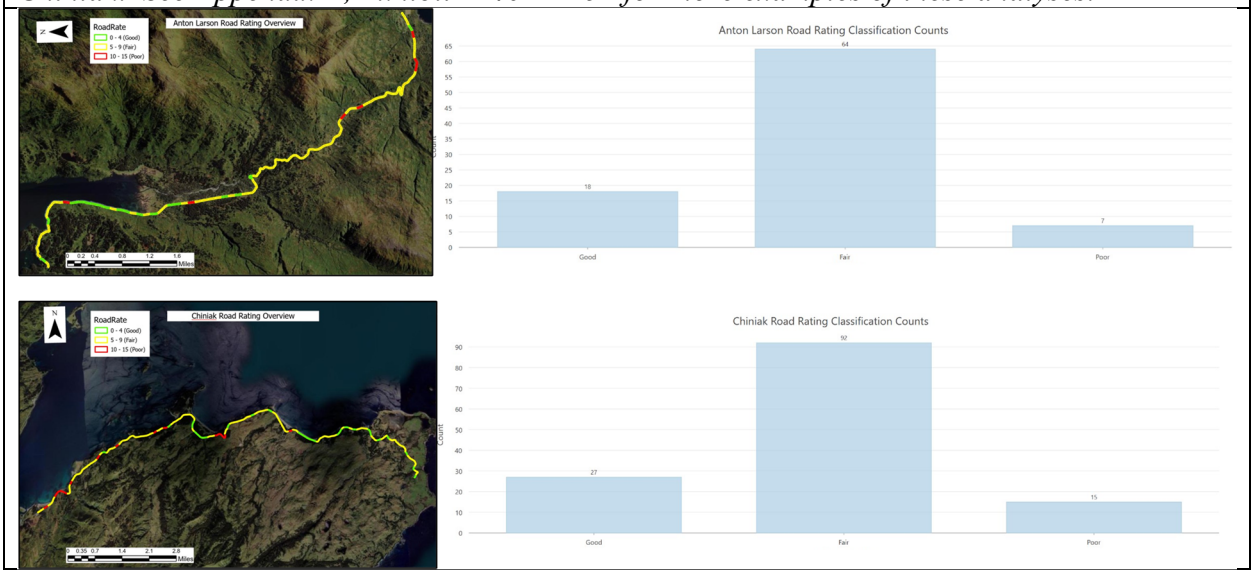
Figure 14: Example of road rating system displayed with secondary assets, road surface hydrology, washboard, potholes, and cross-sections. See Appendix B, Exhibit B-36 through B-39 for additional examples.



Additional statistical analysis of the road conditions is useful to show how road conditions compare across the modeled corridor, or how individual sections compare to the road as a whole (Figure 15). As this rating system is based on quantifiable metrics and analyzed by computer

algorithms, bias from human observations and ratings is removed, allowing for roads from different locations and at different times to be compared to one another through automation and standardization. This work demonstrated the efficacy of the model analyzing the Chiniak data and generating relatively similar results when compared to the results from the training dataset (ALB). This suggests that the metrics can be applied across other project areas to determine gravel road conditions with the existing model parameters. As a result, road conditions can be compared and prioritized for repair based on need and budget without human bias.

Figure 15: Example of the statistical results for the road rating results across both ALB and Chiniak. See Appendix B, Exhibit B-40 – B-52 for more examples of these analyses.

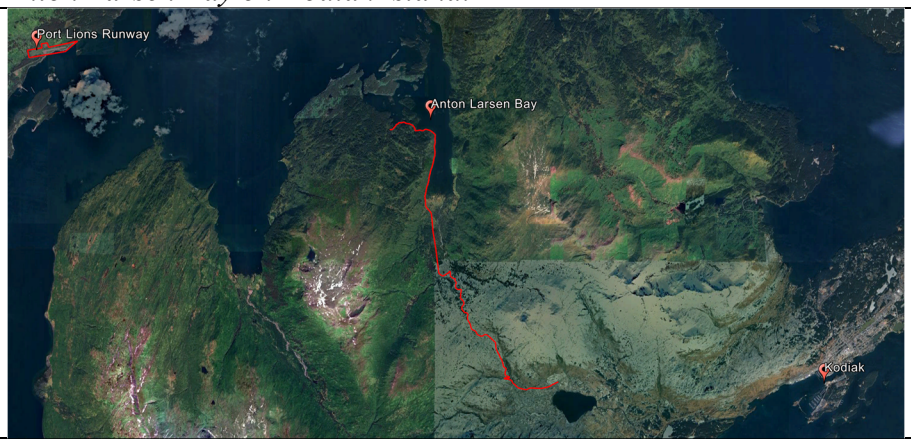


The ingestion of this information into the DOT&PF workflow was not thoroughly explored, however the information extracted and made available through this analysis was very well received and is anticipated to make an impact.

9.0 Gravel Runways

Gravel runways are critical assets for many rural communities across Alaska and are the only point of access for medical supplies, food, and other necessities. DOT&PF expressed interest in applying the gravel road analysis methods to gravel runways to support routine inspections. The Port Lions runway is located west of Anton Larsen Bay and is a short charter flight (~10 minutes) from Kodiak (ADQ) airport to Port Lions (Figure 16). The entire runway area was collected with both LiDAR and imagery within 3 hours of landing on site. The same methods for aerial data collection over the gravel roads were applied for the gravel runway area.

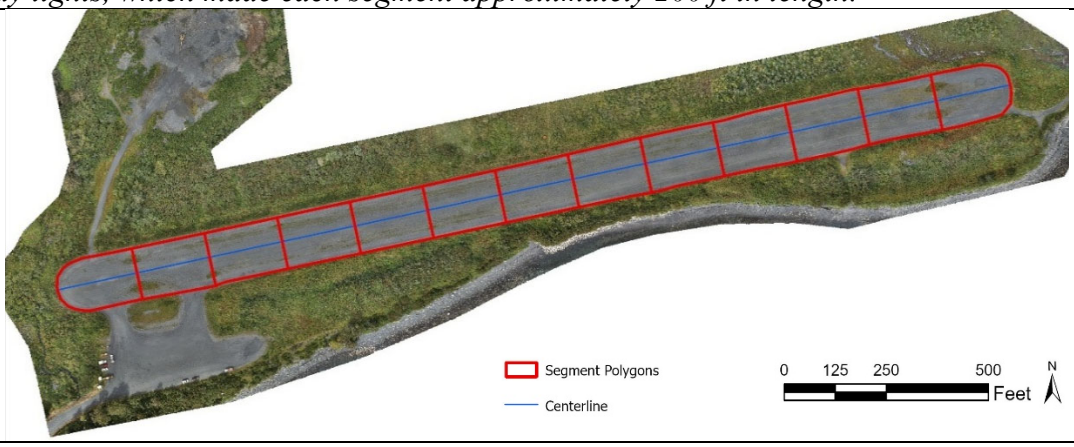
Figure 16: Satellite image showing the location of the Port Lions gravel runway, outlined in red, west of Anton Larsen Bay on Kodiak Island.



The model generated for gravel roads was designed to be highly adaptive, knowing that the metrics defined in table 8 could change depending on the type of infrastructure being analyzed or the end user. This simplified the process to investigate the feasibility of conducting a similar analysis on a gravel runway.

The first step was to digitize the runway in both imagery and LiDAR datasets, followed by generating a geometric centerline and equal segments across the entire runway (Figure 17). This provided the initial framework for the model to be applied to this type of infrastructure.

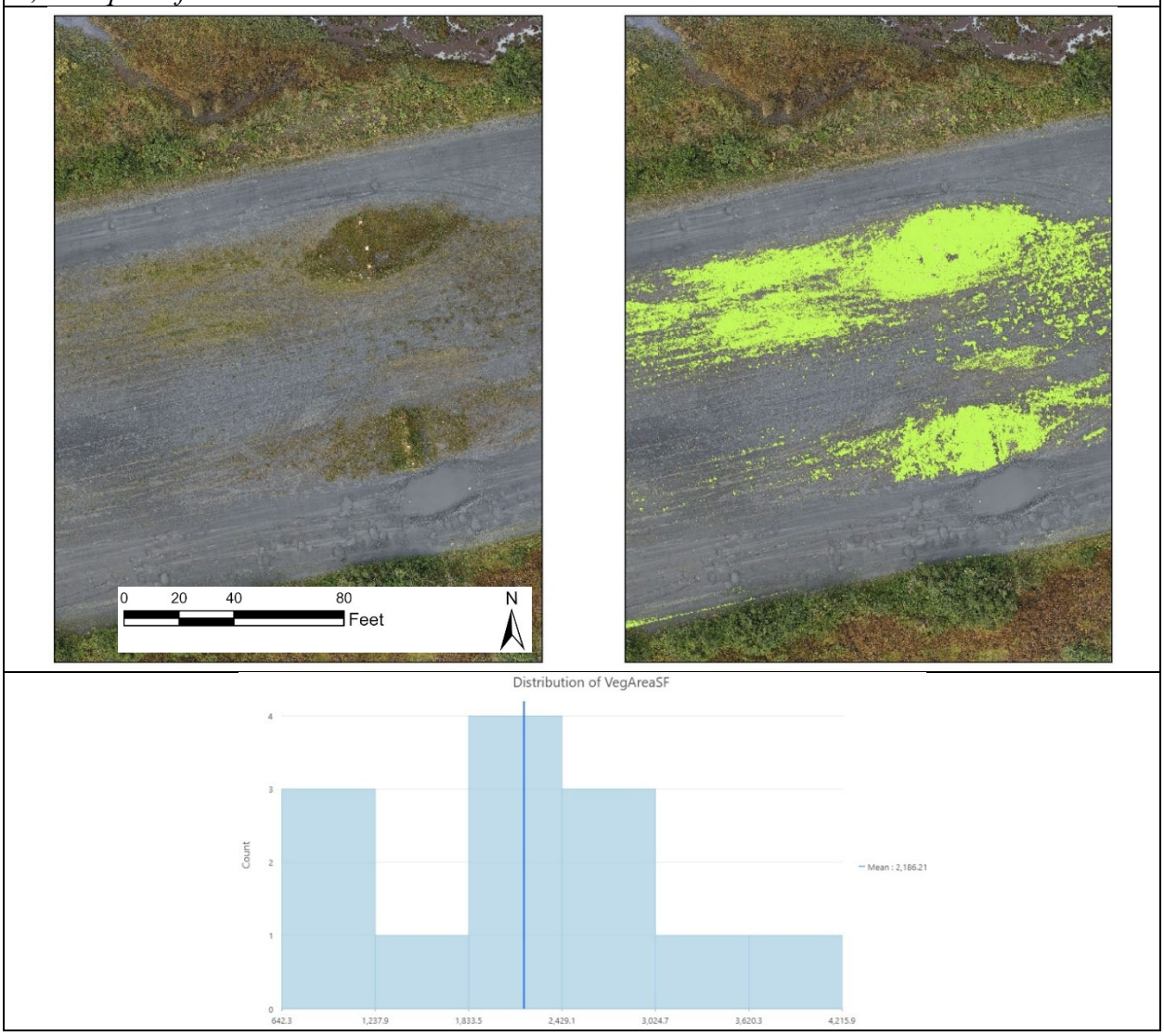
Figure 17: Orthomosaic image illustrating the geometric centerline and the segmentation of Port Lions gravel runway. Segment boundaries were defined where there were installed runway lights, which made each segment approximately 200 ft in length.



9.1 Vegetation Classification

It became apparent that vegetation needed to be added as a new criteria field for the gravel runway model, as vegetation appears predominantly present in the areas around the installed runway lights (Figure 18). Image recognition of vegetation was highly successful, and a vegetation area was calculated within each individual segment. The statistical distribution of vegetated areas is shown in Figure 18 and demonstrates the ability to compare vegetation by segment across the entire gravel runway.

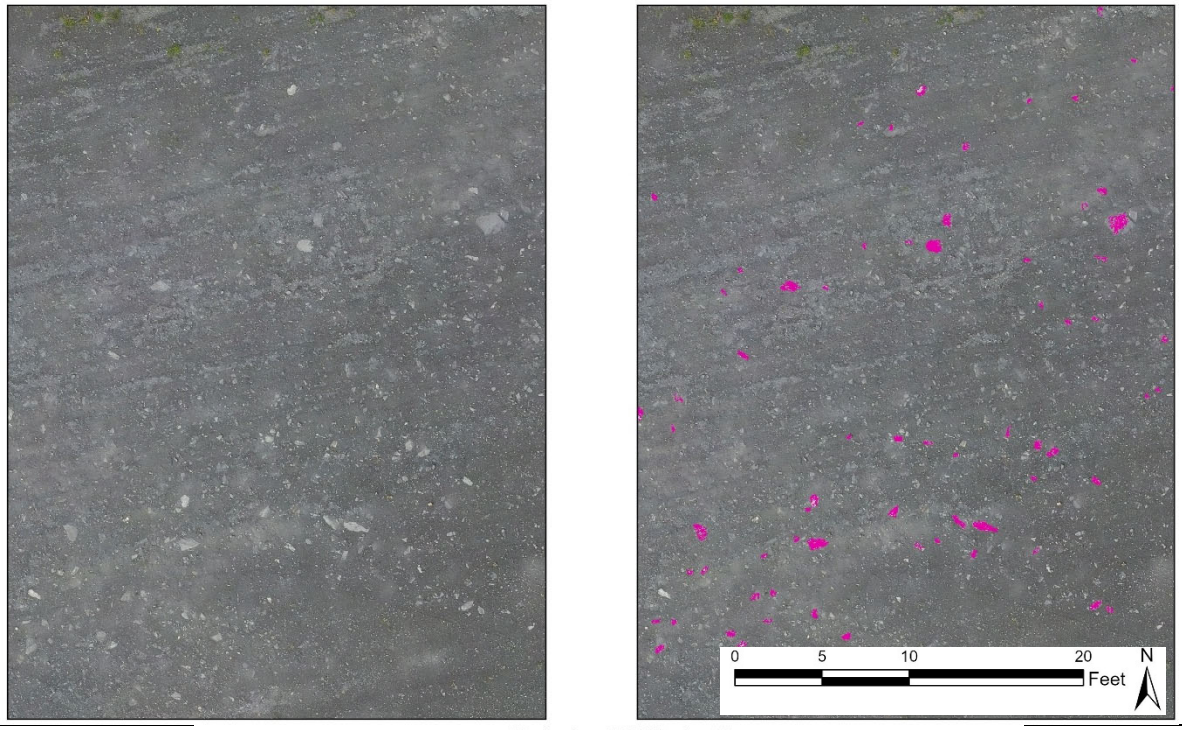
Figure 18: Example of the vegetation on the gravel runway demonstrating the concentration of vegetation and proximity to the runway lights. The left image is the orthomosaic and the right image are the results from the vegetation classification analysis. This allows the vegetation area to be computed within each runway segment. The bar chart below is the statistical distribution of the vegetation surface area computed across the entire runway within each segment, with a total of 13 segments. The mean surface area covered by vegetation is 2,186 square feet.

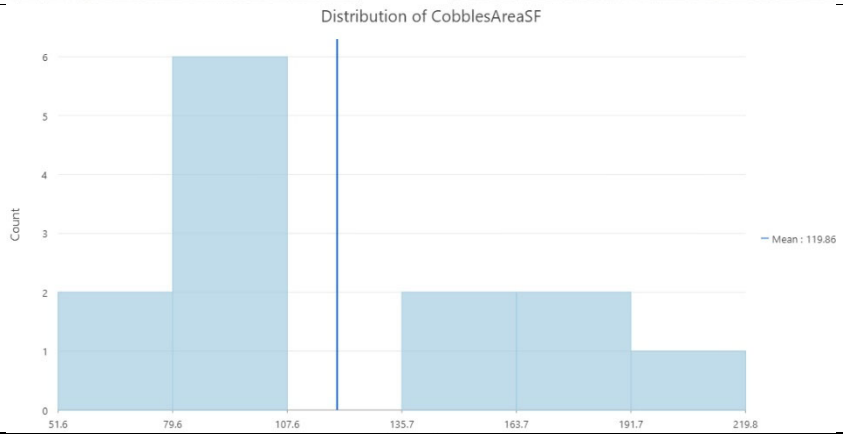


9.2 Cobble Detection

The cobble analysis had a higher success rate than in the gravel road version of this model (Figure 19). This could have been related to the cobble metric being adjusted (cobble defined as ≥ 1.5"), better lighting conditions in the imagery, different color contrast of aggregate vs cobbles, or a combination of all these factors. The detection and calculation of cobbles on the runway surface could be expanded upon to reveal more useful information about this type of infrastructure. For example, if the model can be refined to measure surface area of various particle sizes, this can support maintenance activities for re-grading the runway.

Figure 19: Cobble modeling results were improved on the gravel runway analysis, providing more context for the surface area of cobbles to be analyzed and compared across the runway. The two images below illustrate the imagery on the left and results of the cobble analysis on the right (cobbles highlighted in pink). The statistical distribution of the cobble surface area calculated within each segment is shown in the bar chart below.



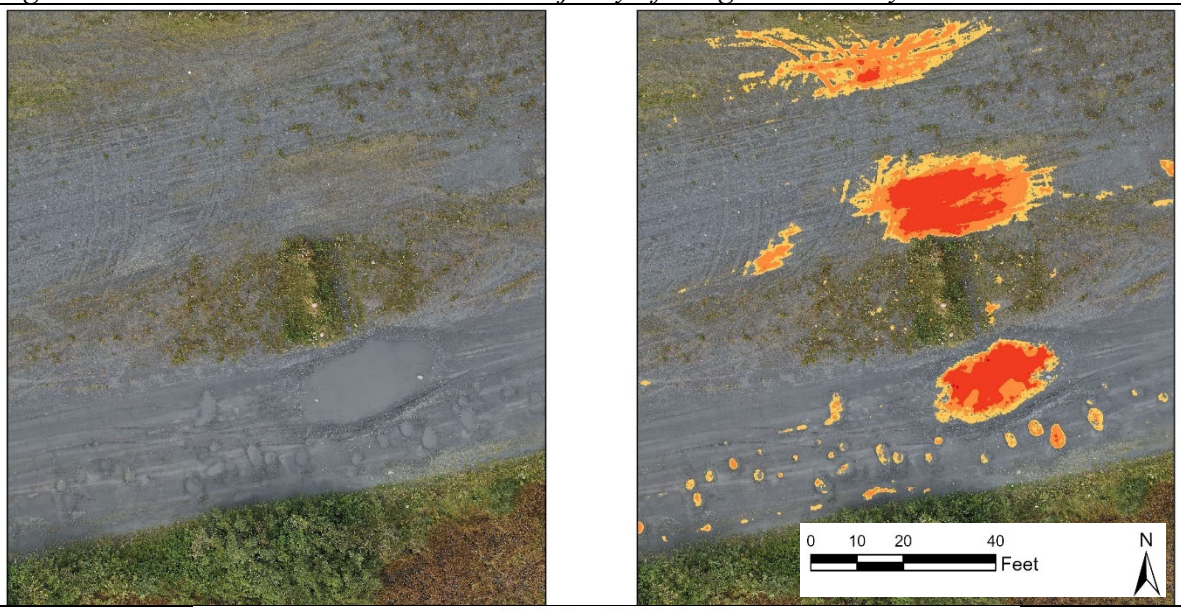


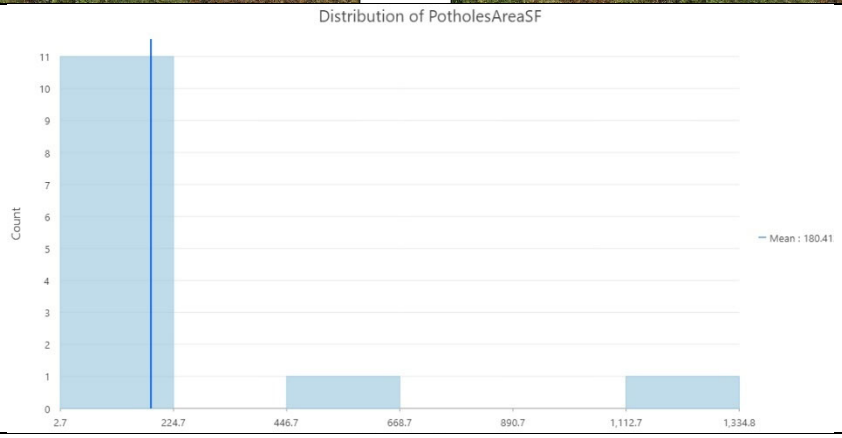
9.3 Potholes

The metrics used for the pothole analysis were adjusted, as FAA specifications have a lower tolerance for potholes being on an active runway. The more sensitive pothole detection analysis worked well, but also detected tire ruts in some instances, which was considered a miss-classification in this context (Figure 20). This issue occurred in limited areas and could be manually edited to remove the tire ruts from the pothole classification. Further refinement of the model could resolve this issue by accounting for the shape of the pothole to produce for a more automated analysis.

This analysis can be useful for computing surface area of potholes, as well as fill volume needed to bring the surface up to grade, relative to the adjacent runway surface. Any volume measurements should be considered as an absolute minimum, as there was water filling some potholes, therefore the depth of these features could not be accurately measured.

Figure 20: The images below illustrate the results from the pothole detection analysis while also showing areas where ruts or tire tracks were classified as potholes. The statistical distribution of pothole surface area is shown in the bar chart below, illustrating there are two segments that are outliers relative to the majority of the gravel runway.

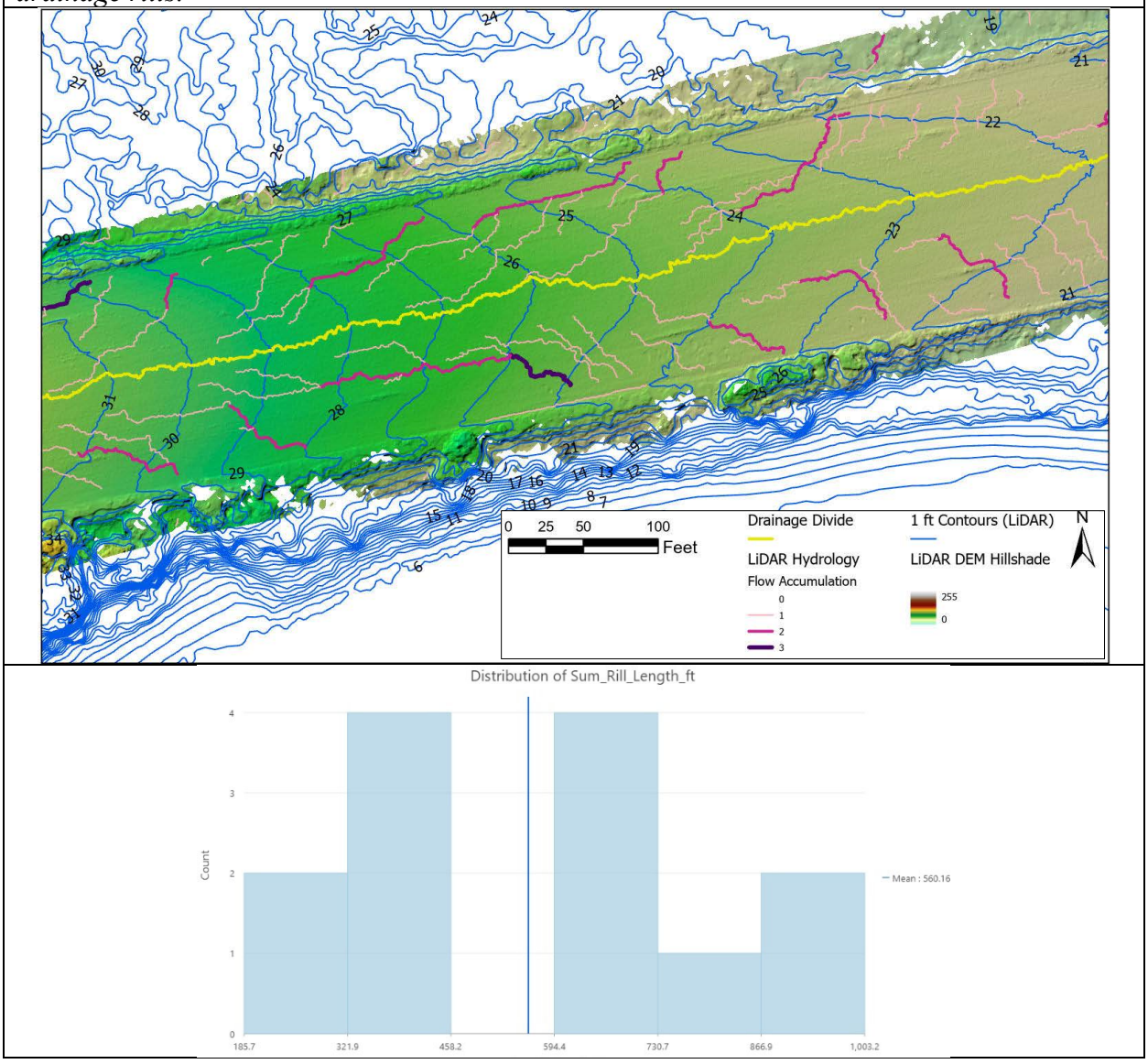




9.4 LiDAR Hydrology Rills

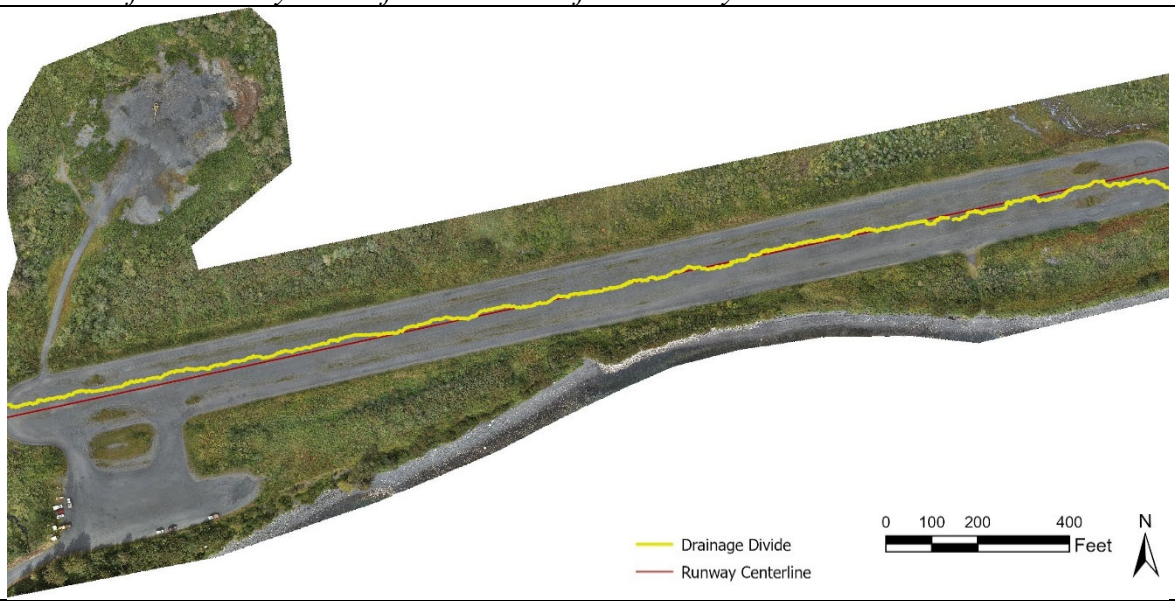
The ground classified LiDAR data was used to generate a DEM of the ground surface elevation across the runway and adjacent areas. Running the hydrological analysis, similar to the gravel road hydrology analysis, identified drainage rills throughout the dataset (Figure 21). These rills were classified within each segment to determine variability across the runway and locate the segments that have the greatest length of rills, which would be indicative of poor drainage on the runway surface. This analysis revealed an apparent "drainage divide," which was not something discernable from the gravel road analysis. This can also be considered as the crown of the runway.

Figure 21: The image below is a false color DEM overlaid by 1ft contours, LiDAR hydrology rills, and the drainage divide dissecting the gravel runway. The bar chart below indicates the distribution across the runway segments, highlighting the segments with a high length of drainage rills.



The proximity of this calculated drainage divide to the geometric centerline varied from one end of the runway to the other (Figure 22). Since there are no known metrics for this type of analysis, it is unclear whether this drainage divide feature and its proximity to the geometric centerline has any significance or can benefit routine inspection or maintenance activities.

Figure 22. Orthomosaic of the gravel runway, illustrating the geometric centerline of the runway and the calculated drainage divide. The distance of this drainage divide to the centerline of the runway varies from one end of the runway to the other.



9.5 Slope

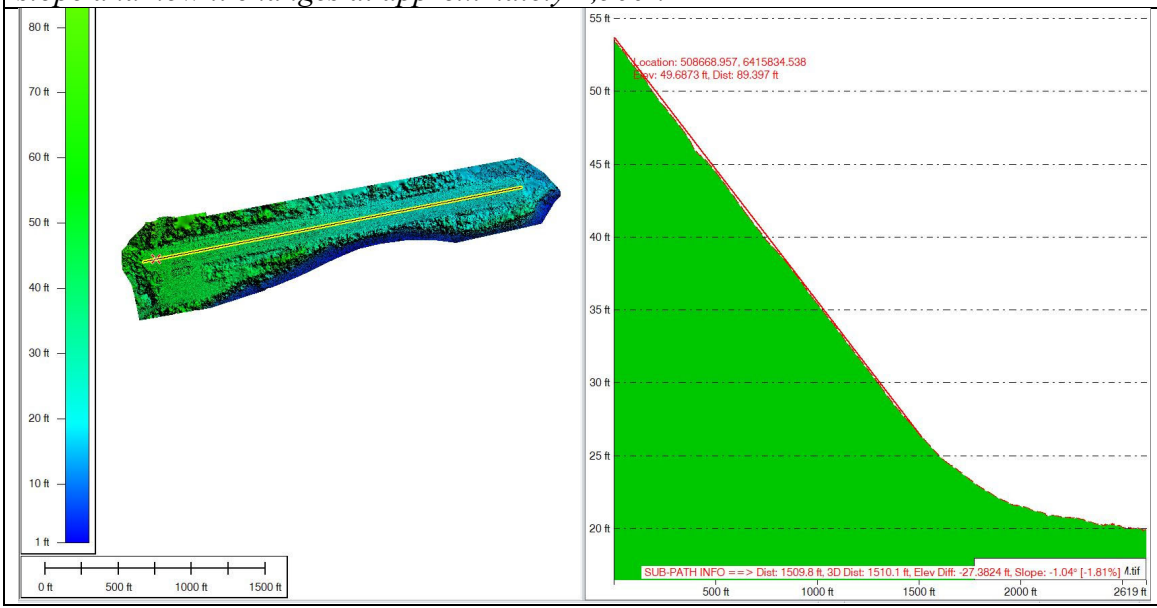
Slope was measured in two different ways across the runway surface; (1) perpendicular to the runway, and (2) parallel to the runway. These measurements relied on the digitized runway surface, segment boundaries, and LiDAR DEM. The min and max elevations along each cross-section line were used to define the crown height, then applied to the following slope formula: Slope = (Crown Height/Cross Section Length) x 100. Perpendicular slope was measured in two different areas within each segment, in a similar fashion to the gravel road model, while the parallel slope was measured along the centerline from one segment boundary to the next (Figure 23).

Figure 23. The orthomosaic image below illustrates the slope calculations across the gravel runway. The perpendicular slope is shown on either side of the centerline (yellow), while the parallel slope is shown along the centerline (blue).



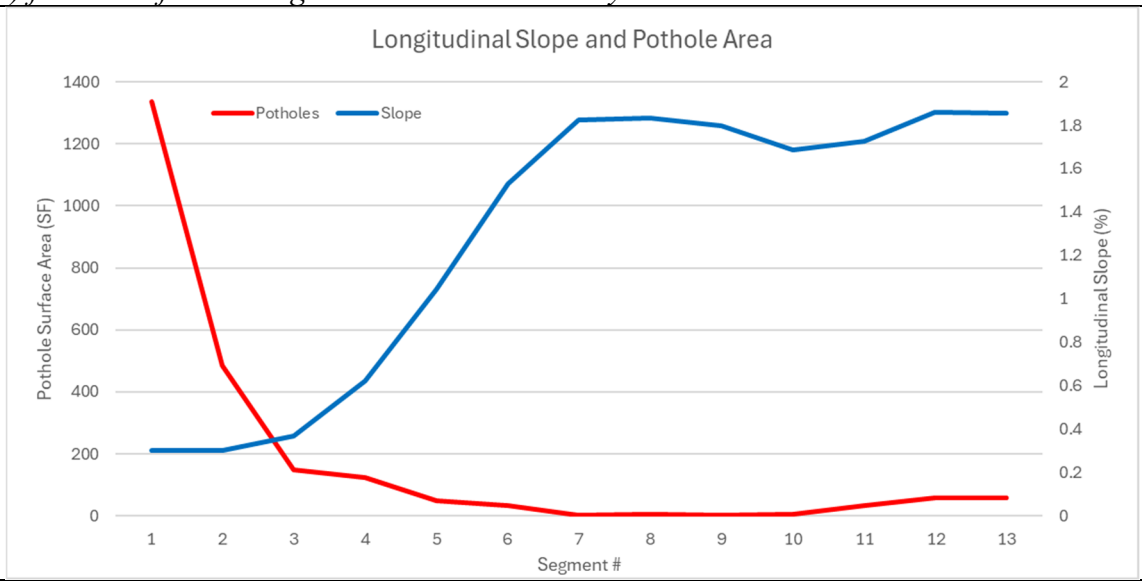
The slope calculations were generated to better understand how the slope varies across the entire gravel runway. Figure 24 shows the longitudinal profile of the gravel runway illustrating how the slope varies from west to east along the centerline. The slope of the runway is consistent for approximately 1500', then flattens out on the eastern 1,100'.

Figure 24. A false color image of the LiDAR DEM was used to illustrate the entire runway slope and how it changes at approximately 1,500'.



The eastern segments of the runway have a higher surface area of potholes (segments 1-3), suggesting that the low slope values of the runway on the eastern 1,100' may correlate to pothole surface area. Figure 25 used pothole surface area plotted with longitudinal slope, to demonstrate the correlation of low longitudinal slope (0.3-0.5%) with pothole surface area.

Figure 25. The graph below plots pothole surface area (red line) and longitudinal slope (blue line) for each of the 13 segments across the runway.



10.0 Data Delivery

All data was processed and delivered in NAD 83 State Plane Alaska 5 FIPS 5005, US Survey Feet and the vertical datum was NAVD88, US Survey Feet. All data derived from the modeling is stored in an ArgGIS geodatabase, zipped and shared with DOT&PF for download and ingestion into their system. The raster files used as inputs for the model are also provided in raster format and very useful for inspecting and reviewing the results of the modeling. File formats are all standard GIS file types and easily ingested into any GIS software package. Table 10 below lists the layers, layer type, format, and a brief description of the processed deliverables files that were shared with DOT&PF.

Table 10 summarizes the files that were generated from the modeling through this work. The orthos, DEMs and pointcloud data were considered inputs, while the remaining files were generated as outputs and stored in the geodatabase (.gdb) file for Chiniak and Anton Larsen.

Layer	Layer Type	Format	Description
Orthomosaic	Raster	.sid	3-band tiled orthomosaic with approximate 270 foot swath width
Ortho clipped to road	Raster	.sid	3-band orthomosaic clipped to road surface, with approximate 22 foot swath width
LiDAR Pointcloud	Pointcloud	.laz	Classified LiDAR pointcloud
Photo DEM	Raster	.tif	Elevation clipped to road surface derived from imagery, with approximate 25-30 foot swath width
LiDAR DEM	Raster	.tif	Elevation surface of ground classified LiDAR with approximate 450-500 foot swath width
Culverts	Polygon	.gdb	LiDAR-Detected Culvert location with estimated width (inches) attribute
Guardrails	Line	.gdb	LiDAR-Detected Guardrail location with estimated length (feet) attribute
Imagery_Hydrology	Line	.gdb	Photo DEM Derived Hydrology "Rills" - Roadway only
LiDAR_Hydrology	Line	.gdb	LiDAR DEM Derived Hydrology "Rills" - Roadway plus buffer
Pothole_Reclass	Raster	.gdb	Photo DEM Derived Potholes (Binary Raster, location/area only)
Road_Boundary	Polygon	.gdb	LiDAR-Derived Roadway Boundary (Edge of Gravel Surface)
Road_CL	Line	.gdb	Geometric Centerline of Road_Boundary Polygon layer
Road_Cross_Sections	Line	.gdb	Cross Sections sampling locations for roadway width, slope, crown & ditch (2 per segment)
Road_Signs	Point	.gdb	LiDAR-Detected Road signs - location only
Summary_Polygons	Polygon	.gdb	Tenth-Mile Roadway Segments containing road rating and all summary attributes/analysis results
Washboard	Line	.gdb	Imagery-Detected washboarding in roadway with length (feet) attribute

11.0 Recommendations

It is highly recommended to make a public service announcement notifying the community of the scheduled activities prior to any aerial operations taking place. Due to the remote nature of this work and the concerns of trespassing by residents in the community, it is important to communicate the purpose of the low flying aircraft. Stating the approximate operational

schedule, type of information being collected, and the overall purpose of the work can drastically reduce any potential risks for local residents to confront the operators while in the field.

Results from the machine learning analysis and dynamic software improve through the processing of additional data, this will further refine the results and methods, leading to increased proficiency and reliability of the modeling results. Imaging additional gravel roads, with variable conditions, will provide more statistical information, which can be used to modify rating metrics and analytical methods to highlight critical conditions. Year over year collection and analysis of data will provide information on the evolution of the road system through time. This will include vertical and horizontal changes to road features, efficacy of repair and maintenance methods, as well as the ability to develop better construction practices that could increase the resilience of the road. Assets that are consistently rated low and in need of continued maintenance will be highlighted in the statistics, allowing stakeholders to better plan for, or investigate, a long-term solution.

While the rating system used in this project is sufficient for use on quantifying and prioritizing gravel road (and runway) conditions, it can be further refined. Elevate recommends that future versions include a "weighting" of features. This will allow conditions that may impact the function of the asset in a more profound way to have a larger impact on the overall section rating. This would require additional insight and discussion with the stakeholders to determine what conditions are priority and how they might be weighted relative to other features. After this determination the program can easily be adjusted and new outputs generated.

Review of the data showed that the road width varied over the length of each road corridor. Currently the profiles used to determine the crown and slope data and apply a rating are fixed (see Section 2.0). The result is a measurement that might not accurately reflect the features measured in areas where the road is wider or narrower than the designed width. As such, Elevate is working on a dynamic measurement method that will account for these variations in road width. This will be fully developed in the next version of the software.

Elevate recommends that this program be developed as a "webhosted" platform. This will allow users to log on to the platform and extract the information they require without specialized hardware, software, or experience with geospatial modeling platforms. Further this would allow users to view the most recent versions of the analysis and data without additional downloads.

12.0 Limitations and Standards of Care

The scope of work did not include providing any recommendations on the condition of site materials, structure, or any other subsurface materials. Data was not compared to the structural drawings or plans, and no comments on the adequacy or correctness of the elements were made.

It should be noted that, as with any geospatial, imaging, or geophysical method, the process relies on instrument signals to indicate physical conditions in the field. Signal information can be affected by on-site conditions beyond the control of the operator, such as, but not limited to, material type, lighting conditions, and/or the shape of the object(s). Interpretation of those signals is based on a combination of known factors combined with the experience of the operator

and geospatial scientist evaluating the results. We cannot be responsible for the misinterpretation of unverified geospatial results by others.

The accuracy of our findings is subject to specific site conditions and limitations inherent to the techniques used (as described above). Elevate performed these services in a manner consistent with the standard of care ordinarily exercised by members of the profession currently employing similar methods. Since the results of geospatial data collection methods are dependent on the synthesis and interpretation of many variable physical, structural, and electromagnetic phenomena, neither Elevate, nor any of its employees, make any warranty, express or implied, nor assume any legal responsibility or liability for the accuracy, completeness or usefulness of any information, apparatus, product, or process.