North Slope Borough
2018 LiDAR Planning
LiDAR Pilot Dataset Review and Application
Task 1 Report

NSB Project No. 2019-021

December 2018

Final

12/10/18

Incorporated July 2, 1972

Prepared For:
North Slope Borough

Prepared By:
Kinney Engineering, LLC
3909 Arctic Blvd, Ste 400
Anchorage, AK 99503
907-346-2373
AECL1102

Charles E. Barnwell, M.S.

TABLE OF CONTENTS

List of Figures

Acronyms

AOI	Area of Interest
AOOS	Alaska Ocean Observation System
ASPRS	American Society of Photogrammetry and Remote Sensing
DEM	Digital Elevation Model
DNR	Department of Natural Resources
DTM	Digital Terrain Model
FEMA	Federal Emergency Management Agency
FNSB	Fairbanks North Slope Borough
GIS	Geographic Information System
GPSC	Geospatial Products Service Contract (USGS managed)
GSD	Ground Sample Distance
LiDAR	Light Imaging, Detection, and Ranging
MSB	Matanuska Susitna Borough
NRCS	National Resources Conservation Service
NSB	North Slope Borough
QA	Quality Assurance
QC	Quality Control
QSI	Quantum Spatial Incorporated
RFQ	Request for Qualifications
RFP	Request for Proposal
RGB	Red, Green, Blue
SDMI	(Alaska) Statewide Digital Mapping Initiative
USACE	U.S. Army Corps of Engineers
UAV	Unmanned Aerial Vehicles
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
URISA	Urban and Regional Information Systems Association
YK	Yukon Kuskokwim

Executive Summary

This report describes the results of Kinney Engineering's (KE) review of 2018 Pilot Delivery LiDAR data as part of the 2018 USGS/NSB LiDAR Project. Additionally, KE reviewed potential applications of LiDAR data to NSB needs. Utqiagvik (formerly known as Barrow) was chosen among the seven villages acquired in 2018 as the location for the Pilot LiDAR study. The review was conducted using the preliminary 2018 pilot LiDAR datasets provided by USGS and its contractor Quantum Spatial Incorporated (QSI), to the North Slope Borough (NSB). The Pilot project includes development by KE of a drainage and flood control analysis using the 2018 Pilot data. This type of application is considered to be of immediate and priority need due to concerns about coastal erosion and other ongoing climate change effects. The KE study is an independent third-party assessment to check for any collection and/or processing or acquisition errors, and to check for suitability of the data for hydrologic and other public works type purposes in the Utqiagvik area. This report is one of six reports produced by KE as part of the 2018 NSB LiDAR project, addressing different parts of the NSB LiDAR implementation.

KE did not check for LiDAR accuracies comparing survey points for vertical accuracy, as this analysis and review is being done by USGS. However, we did review and request from USGS/QSI a separate analysis of accuracy statistics. The assessments in this report found that at a minimum the LiDAR data meet the United States Geological Survey (USGS) Quality Level (QL) 1 based on a review of QSI's report. The data also met specifications as outlined in the project kickoff meeting in July, 2018, and typical USGS 3DEP program requirements. The Pilot LiDAR data were acquired in mid-September, 2018 during conditions of minimal snow/ice cover, and meeting USGS acquisition standards.

Our findings from the review of the 2018 Pilot LiDAR data show the following:

1. *LiDAR Data Quality*: overall, classification of the data (ground, vegetation, water), and other key aspects of LiDAR data as considered by the USGS, is very good throughout in the Pilot dataset.
2. *Suitability of the data for North Slope terrain*: The terrain aspects of the Utqiagvik area are complex and challenging due to largely the flat nature of the area, and unique drainage patterns. The QL1 LiDAR data appears very suitable for this terrain and environment.
3. *Survey control* collected to calibrate and ensure LiDAR accuracy appears to meet USGS specifications. It is recommended that these ground control points serve as a control reference for future mapping projects in the Utqiagvik area.
4. *Flood control and risk mapping* was identified as a need late in this project. This LiDAR data is well suited for such work.

A secondary goal of this study was also to review how other local governments in Alaska, and elsewhere, utilize LiDAR data; and ensure that the LiDAR data is implemented properly at the NSB, and not fall into disuse as many LiDAR datasets are prone to do.

1 Introduction

This report is an independent assessment and test case application of the 2018 Light Detection and Ranging (LiDAR) to NSB needs. The USGS will conduct its own assessment as part of standard 3DEP protocols, once the LiDAR acquisition for all nine areas is complete.

Overall, the 2018LiDAR Planning project addresses LiDAR implementation at the North Slope Borough (see Figure 2 below). As shown in Figure 2, the NSB is nearing completion of Stage 1—acquisition of data. This Pilot Review is an initial task that typically is in the midpoint in LiDAR implementation; and this will prove useful for guidance of activities in the middle stage of LiDAR implementation.

The purpose of this KE Pilot project and study is two-fold:

1. To review the pilot dataset provided to the NSB by the USGS through its contractor QSI. This consists of a brief review of the content of the pilot dataset, quality, and how well it can be applied to NSB needs, specifically erosion and drainage.
2. To demonstrate applicability of the LiDAR data to a major business need of the NSB, by performing drainage analyses of the Utqiagvik area using the LiDAR pilot data, and generating a number of products illustrating the hydrologic nature of the area.

As part of the NSB/USGS 2018 LiDAR project, data was acquired for seven of the nine villages and areas of interest (AOI). The LiDAR data acquired in 2018 is high resolution (USGS Quality Level 1 (QL1), and Quality Level 2 (QL2)). The 2018 LiDAR project is a partnership between the NSB and the USGS. The 2018 NSB/USGS LiDAR acquisition is a USGS 3DEP project funded by the USGS and the NSB. Beyond the funding input, the USGS partnership also provides the support of the USGS expertise and program, ensuring the data meets national standards, and providing an authoritative basemap for North Slope communities. The NSB/USGS LiDAR dataset will be public domain.

The USGS graciously agreed to providing the NSB with a pilot project delivery thus allowing the NSB and KE to get “our feet wet” becoming familiar with QL1 data in this area; and with processing of the data, and application of the LiDAR data to a critical need of the NSB prior to delivery of the entire LiDAR datasets.

Besides reports, KE and the NSB GIS held a number of LiDAR project meetings with various groups and agencies. See Section 8 – References.

Figure 1. North Slope Borough and proposed (mid-2017) acquisition AOIs

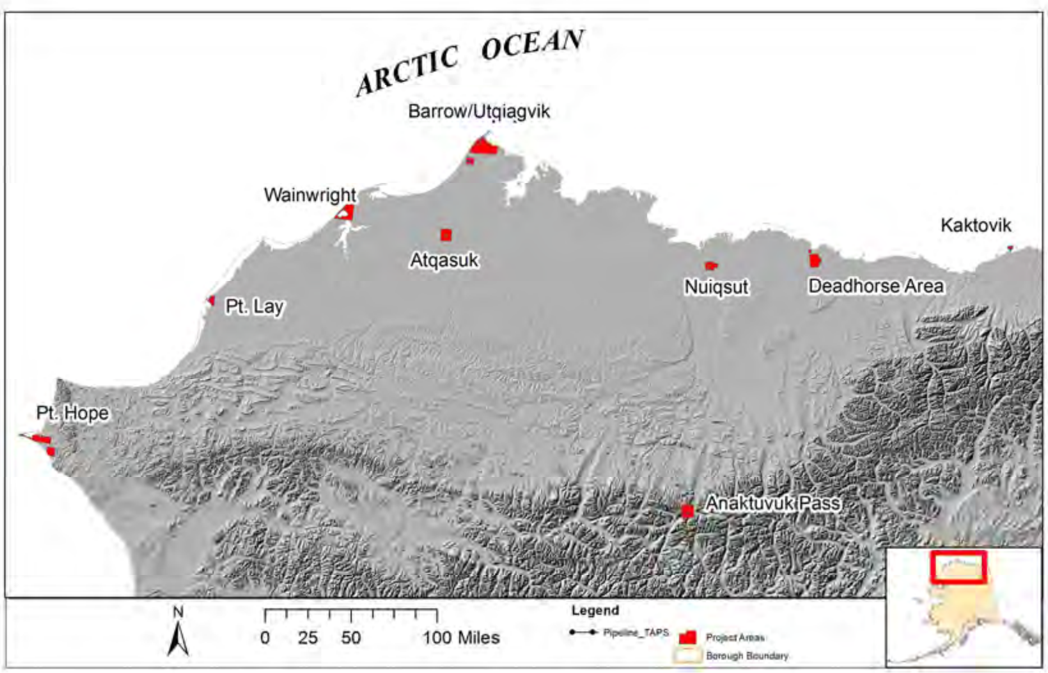
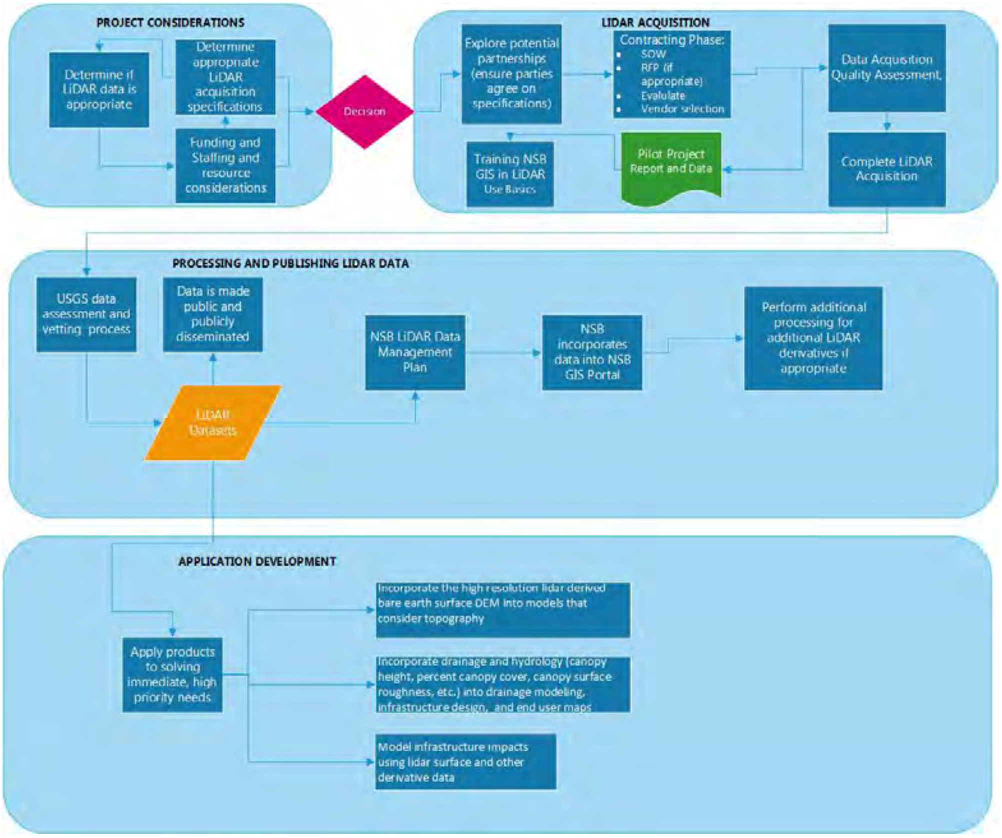


Figure 2.LiDAR Implementation Workflow



2 Applications of LiDAR

In summary, general uses or applications of LiDAR in local governments fall into the typical categories described below. From the LiDAR data, some organizations for example have been able to generate a high-resolution mapping of terrain, rivers and streams, geocoded buildings, calculated elevations for buildings; and produced flood control and drainage models. Leveraging the LiDAR data, organizations, with regard to flood control, drainage, erosion and the like, have been able to seamlessly understand the volumes of water present, and where water will flow during flooding and subsidence scenarios.

Among these applications, we have focused in the short term on immediate applications of terrain analysis and hydrologic mapping. See also the Kinney Engineering 2017 LiDAR and Imagery Needs Analysis, and the 2018 Task 2B Report for description of other LiDAR applications.

Archaeology:

- Detailed terrain mapping revealing hidden cultural features
- Along with remote sensing imagery analysis (e.g. Ground Penetrating Radar), reveals patterns otherwise unrecognized

Cadastral:

- Facilitating integration of survey and survey control data with GIS
- Providing vertically and horizontally correct basemap
- Correction of the cadastral "fabric" helping to correct property boundary maps, and etc.

Emergency management

- Hazards assessments and support,
- Storm impacts and before and after analysis,
- Accurate flood plain delineation,
- Slope failure risk analysis,
- Earthquake fault mapping

Infrastructure (above ground) mapping

Buildings:

- Building height and footprint
- Roofing type
- Determine lines of site
- Site design, planning
- Location of boundaries and features
-

Transportation:

- Generally, provision of accurate DTM data for design and planning
- Road construction
- Aviation
- Water-borne coastline mapping

Terrain or Topographic:

- Baseline topographic mapping
- Elevation mapping and polygons with elevation attributes (digital elevation model)
- Hydrologic: water bodies and features (lakes, streams, rivers, and other)

Utilities:

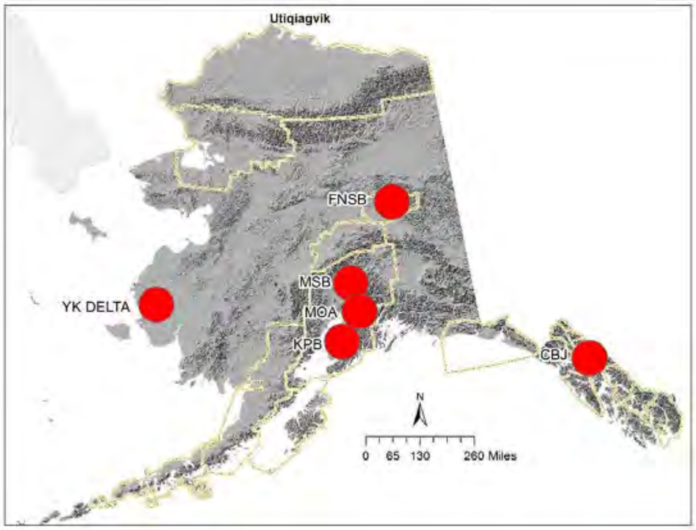
- Electric,
- storm sewer, hydrant, etc.

Water:

- Hydrologic GIS models
- Detecting micro-depression wetlands
- Watershed planning and watershed delineation
- City drainage mapping
- Determining impervious surfaces

For the applications listed above LiDAR is increasingly being invested in, and used, by local governments. Alaska is no exception. Figure 3 below shows key local governments who have invested in LiDAR to date.

Figure 3. Other Alaska Local Governments investing in LiDAR 2002--2017



2.1 Key NSB Application Focus - 2018

2.1.1 Public Works and Engineering

Other organizations have utilized the combination of LiDAR-derived DTM and digital imagery for digital mapping of infrastructure. The applications include asset management, right-of-way alignment, terrain modeling, and other transportation applications. The application of remotely sensed digital data (both LiDAR and imagery) accelerates data collection and processing efforts, which are essential for full and timely implementation of geographic information system (GIS) based infrastructure asset management systems.

For engineering work, such data can be loaded into terrain mapping or computer-aided design software, allowing further applications to be developed. Horizontal and vertical accuracy of LiDAR data is radically better than traditional mapping methods, and getting even better. See Appendix B for a summary of Utqiagvik pilot data statistics.

In public works type applications LiDAR data have been used to locate asset features such as road centerlines, road crossings, utilities, and culverts for mapping purposes, as well as basic digital terrain model (DTM) development. The data allowed engineers to analyze terrain and structure conditions, measure distances between features, design, and develop plans.

With high resolution and accuracy, LiDAR-derived digital elevation models (DEMs) have been increasingly used for watershed analyses and modeling by hydrologists, planners and engineers. Such high-accuracy DEMs have demonstrated their effectiveness in delineating watershed and drainage patterns at fine scales in low-relief terrains. However, these high-resolution datasets are usually only available as topographic DEMs rather than hydrologic DEMs, presenting greater land roughness that can affect natural flow accumulation. Specifically, locations of drainage structures such as road culverts and bridges can be simulated as barriers to the passage of drainage (see Section 4) .

3 Project Area and Deliverables Received

As part of the NSB/USGS acquisition, high-resolution LiDAR data were collected over the Utqiagvik in September, 2018. Figure 4 below shows a location map of the Pilot area. The Utqiagvik pilot area, covering pproximately 14 square miles of was selected in July 2018 by consensus of the NSB,USGS, QSI, KE LiDAR team for a number of reasons:

1. Representative of key north slope coastal and hydrologic features,
2. Characteristic coastal plain terrain,
3. Village infrastructure, and
4. Prominence as the main community of the NSB at risk of flooding.

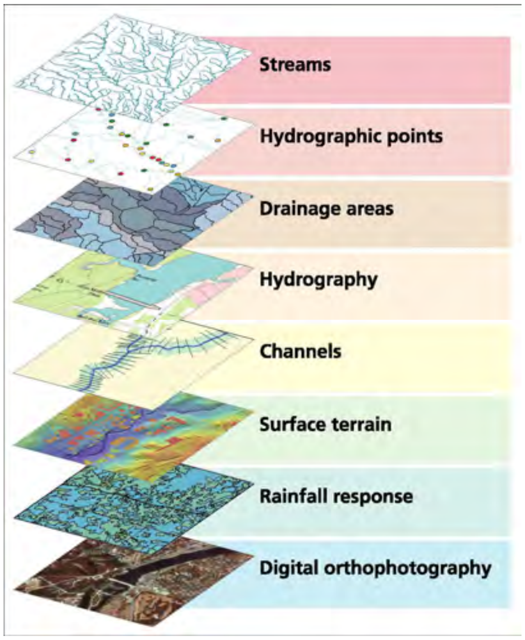
Quantum Spatial Inc. delivered the Pilot data to the NSB and Kinney Engineering on November 13, 2018. The purpose of the KE part of the Pilot project is to evaluate LiDAR-derived terrain information in terms of general quality, and compared to existing terrain information; and also demonstrate how the data can be used by the NSB, for example support of the design of a sea wall. See Appendix B for a list of Pilot deliverables from QSI.

The Pilot project area was chosen by the NSB/USGS/QSI/KE team based on criteria including community structure and parcel data availability, and new LiDAR data (collected in Sept.2018) surpassing existing elevation and other similar data.

As shown in Figure 5 below, a key application of LiDAR involves a number of layers of data to assess they hydrologic setting of a place, in this case Utqiagvik. LiDAR provides data to form most of the layers shown in Figure 5, from stream channels, watershed/basins, vegetation, and topographic terrain. The one data layer not provided by LiDAR is climatic, in this case precipitation.

Figure 4. Location map and extent of the Utqiagvik Pilot LiDAR dataset

Figure 5. Hydrologic Modeling Data Layers



3.1 Approach

This pilot project was initiated to assess the quality of the 2018 high resolution LiDAR data, and to explore the concept of using the data to manage and plan coastal erosion mitigation, and city area drainage in the Utqiagvik area. In this pilot, KE tested the use of LiDAR to perform drainage and flood control analyses, and assess the data relative to features such as NSB culvert locations.

LiDAR is a remote sensing technology that is capable of efficiently creating accurate topographic data on a large scale. Using this LiDAR approach, the NSB can determine culvert locations and other features relative to drainage surfaces at one time. USGS elevation data have been the most commonly used data source for many purposes, including hydraulic analysis and flood risk mapping for example; however, prior to LiDAR coverage, much of the elevation data, especially on the North Slope, was too “coarse” to adequately describe surface profiles of watershed areas or drainage patterns. Another aspect also is that USGS elevation data is often outdated, in Alaska significantly so; and thus did not reflect natural and man-made changes to the earth’s surface. This is a real problem in an area like the North Slope which is seeing major changes.

The pilot project objectives are to produce derivatives of the Pilot LiDAR-derived hydro-enforced digital elevation models (DEMs), which will depict drainages and catchment basins, and other hydrologic features. The processing and analysis KE performed incorporates data collection of drainage structures (i.e., culverts and structures), data preprocessing and to develop a prototype hydrologic model or drainage plan for the city of Utqiagvik. As shown in Figure 5 above, hydrologic modeling using GIS takes into account a number of data inputs. Most of the layers shown in Figure 5 except for climate and orthoimagery can be provided by LiDAR data; and LiDAR intensity imagery can suffice in large part for aerial imagery. Drainage and hydrologic modeling are made difficult in a place like Utqiagvik due to the different nature of the Arctic, e.g. permafrost and other factors which make modeling more challenging, and not using formulaic approaches used in non-arctic areas.

Additionally, hydraulic design requires delineation of much smaller drainage areas (watersheds) than other hydrologic applications, such as environmental, ecological, and water resource management. This project also briefly investigated whether higher resolution LiDAR based surface models would provide better delineation of watersheds and drainage patterns as compared to surface models created from non-LiDAR type elevation data.

3.2 Potential Benefits of the Study

The primary benefit of this study was to determine whether the use of high-resolution terrain data provided by Pilot QL1 LiDAR is suitable for drainage modeling and other tasks such as flood control risk mapping, and in a unique landscape and environment such as that of arctic Alaska. The NSB is characterized by:

- An arctic climate
- Flat terrain
- Tundra
- Permafrost, and
- A Complex hydrography consisting of numerous water bodies and streams

The NSB is approximately 95,000 square miles is one of the largest local governments geographically in the United States. The NSB is a remote area with a low population of approximately 10,000 spread amongst communities distant from each other. Detailed mapping of the NSB is generally lacking, or in places where good mapping does exist, typically this is out of date. The NSB is currently experiencing historically record increased amounts of coastal erosion and subsidence due to the extreme effects of global climate change on the arctic. Given that most of its communities are located in coastal areas, this is a major concern for NSB residents and managers. Having good quality, accurate mapping will be beneficial to engineers, scientists, and others faced with the job of assessing, and dealing with, these changes.

KE determined that the Pilot LiDAR data improves drainage area delineation, and thus will assist in corresponding flow estimates, and this may influence design of hydraulic features such as culverts, and siting of a potential sea wall along the coast. In a flat terrain like Utqiagvik, QL1 data will provide a greatly enhanced mapping of these features.

LIDAR will likely provide the greatest benefit for roads and infrastructure projects in flood and erosion prone areas, and areas with relatively flat terrain where slight changes in terrain may have a significant impact on drainage patterns. If the increased terrain detail from the LiDAR data can improve hydraulic design, structures may be more accurately placed, and cost effectively designed. Possible deficiencies in existing design may also be identified.

Possible benefits of deficiency identification include limiting future system failure, and for example the deterioration of road surfaces and structures resulting from improper drainage. Additionally, this data and derivative products would provide the ability to assess the surety of existing structures particularly since existing data do not adequately delineate existing facilities.

LIDAR may provide possibly valuable detail in areas of modified terrain, such as airports. Better representations of channel and terrain detail in the vicinity of these types of surfaces may be useful in modeling problem drainage areas and evaluating structural surety during and after significant storm events.

4 Methodology

Hydraulic design entails several key components. The components affected by use of terrain models are:

- Drainage area size,
- Topography, and
- Stream channel location.

Differences between size, topography, and location of streambeds/water courses that result from the original terrain and uses of terrain were the focus of this study. Implications of the differences in size, topography, and channel location were also addressed. This study was not a detailed analysis, but intended to demonstrate the usefulness of LiDAR data in assessing Utqiagvik area drainage features.

See Appendix A for definitions of technical terms used in this section.

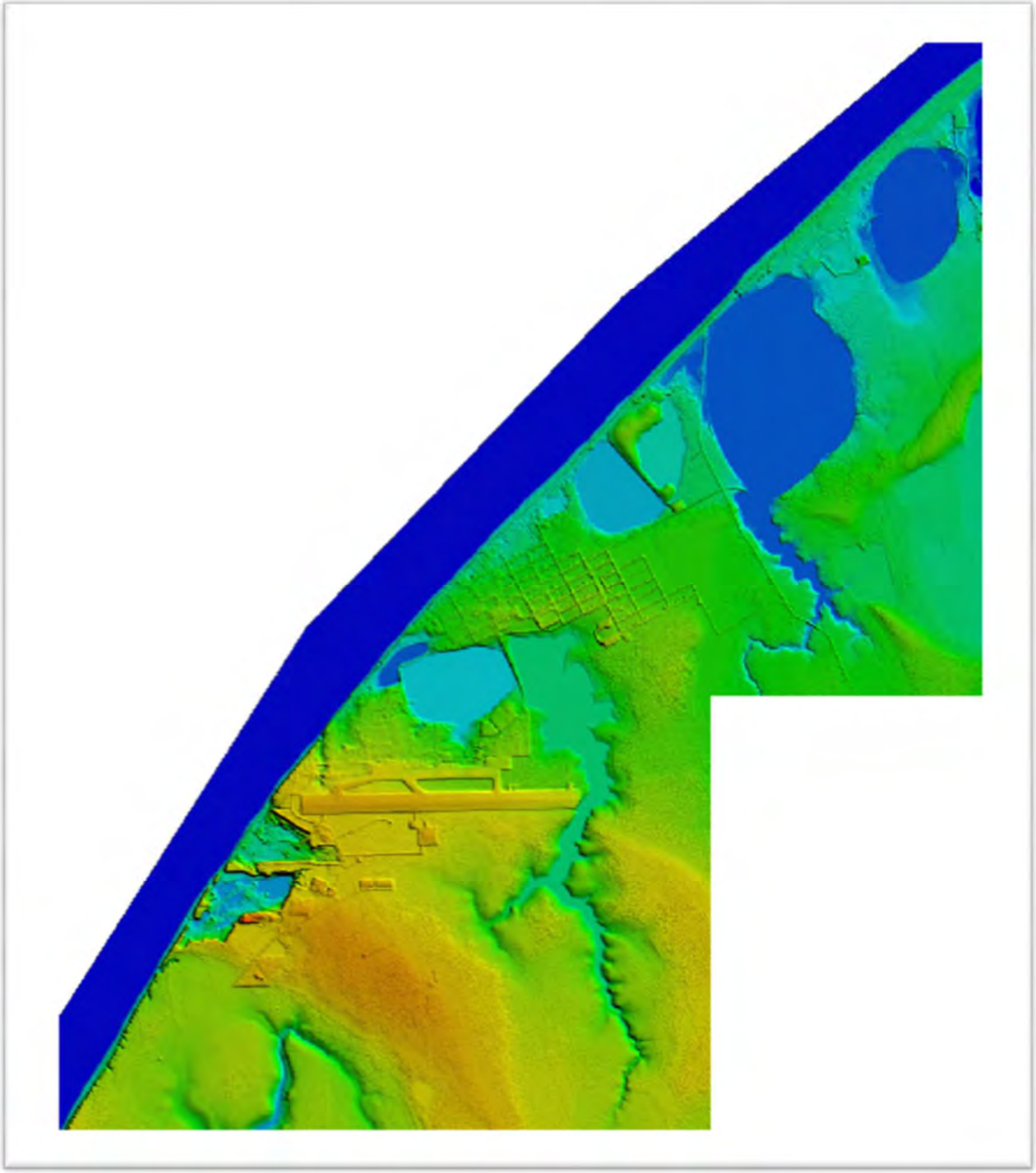
4.1 LIDAR Surface Elevation Models

Since the early 1970s, light detection and ranging (LIDAR) has been used for terrain definition. The LiDAR instrument transmits a beam of light to a target. Some of this light is reflected/scattered back to the instrument. The time for the light to travel out to the target and back to the LiDAR is used to determine the range to the target. LiDAR works best with low vegetation, but even in heavy vegetation some light pulses penetrate and are returned so that the distance to the ground can be measured. Algorithms in software programs (see Section 8) are then used to “filter” out the vegetation and buildings, leaving what is referred to as a “bare earth” digital elevation model (DEM), which contains precise ground elevations. This data is further processed to produce a “hydroflattened” DEM. In the case of the North Slope villages, QL1 resolution LiDAR was desirable given the flat terrain of coastal north slope villages, and to discern subtle drainage and other features.

4.2 LIDAR Bare Earth

Using the LiDAR bare earth data sets, an elevation grid of specified cell size was created by QSI for the pilot area. While a finer grid could be created from the LiDAR data set, given the density of data points this sufficed for processing efficiency and consistency with the pilot data set.

Figure 6. 2018 Utqiagvik LiDAR DEM



4.2.1 LIDAR Bare Earth Supplemented with Culverts

ArcGIS Spatial Analyst® and Global Mapper® were used to derive:

- Watersheds,
- Catchment basins,
- A stream configuration or drainage network, and
- Grids such as a flow accumulation grid.

Our approach was to use two different software programs to ensure we got similar results. Ground truth and survey data were collected in 2018. See Appendix B for a description. See Section 8 for key technical references on procedures and software use.

The culverts were collected using handheld GPS for horizontal accuracy by the NSB. Typically to create a drainage structure dataset, the geographic coordinates of inlets and outlets of culverts and/or center points of the edges of roads are collected using a GPS unit. Only geometrical parameters important for hydrologic modeling are collected during the fieldwork but other engineering parameters such as materials and culvert design critical for hydraulic modeling and structure maintenance could potentially be included in the attributes. Although we didn't incorporate culverts on the grid development and actual drainage flow analyses, we did note culvert locations in placing pour points.

For analysis using raster data, point features must be converted into linear features before the burning process. In this study, the collected paired feature points were assigned with the same Structure IDs (e.g., 1, 2, 3, …, etc.) then converted to line features. This process can be implemented using the Points to Line tool of ArcToolbox in ArcGIS 10. The attributes collected for each drainage structure were joined to the attribute table of the new vector line features. KE used a NSB GIS shapefile for culverts as a basis for the analysis.

4.2.2 Elevation Grids

Before watersheds and streams can be delineated, elevation grids were created from the point-based LiDAR elevation data. An elevation grid or Digital Elevation Model (DEM) consists of a grid of cells, square or rectangular, in raster format having land surface elevation stored in each cell.

Four distinct elevation grids were created for this study. Using Global Mapper and ArcGIS Spatial Analyst, the following grids were created for this elevation grid:

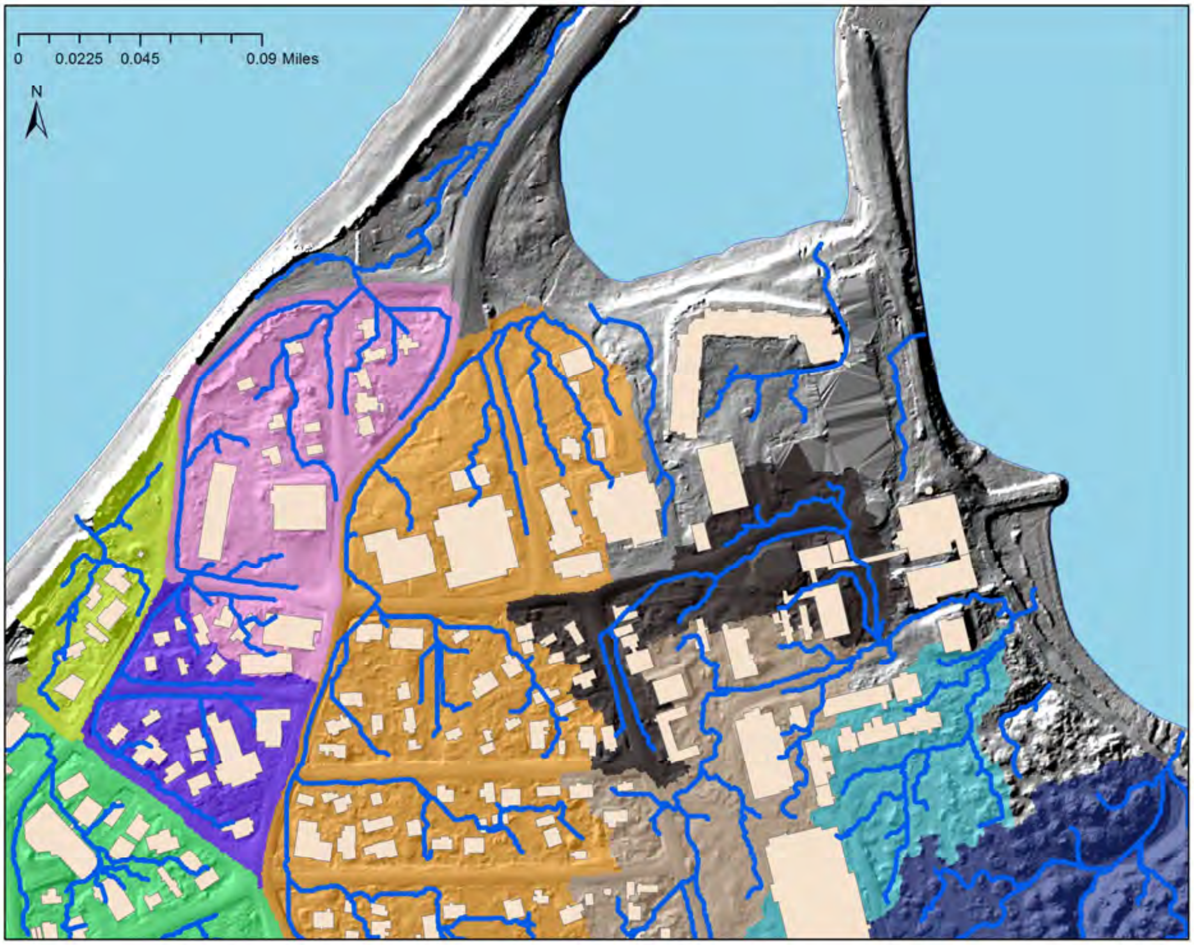
- Depressionless grid (free of sinks),
- Flow accumulation,
- Flow direction

These grids were used with pour points in ArcGIS Spatial Analyst, and secondarily Global Mapper, to delineate and drainage networks catchment basins, and watersheds (see Figures 7 and 10).

4.2.3 Watershed and Stream Creation

As part of this study, we used the Pilot LiDAR data to assess watershed basins and drainages in the Utqiagvik area. Programs such as ArcGIS Spatial Analyst and another extension—ArcHydro-- employ a multi-step process to define streams and watershed boundaries from terrain data. The user has more control in the step-by-step approach, allowing interactive review and verification of the incremental results. A step-by-step or batch processing approach is used to derive the stream and watershed coverages. The batch process develops all incremental and final data sets, allowing only limited user input. This study utilized both approaches. Figures, 7, 10 and 11 shows the result of analyzing streams and basin boundaries using the QSI LiDAR data.

Figure 7. Basins, Water Flow Lines, and Structures



5 Mapping Urban Drainage with Airborne LiDAR

Urban drainage patterns and features were mapped in the core area of Utqiagvik (see Figures 7 10, 11 below). KE has been able to demonstrate that QL1 LiDAR can adequately characterize water flowing across urban and suburban environments in a wide range of terrain types. The resulting highly accurate drainage calculations can be integrated with standard storm water methods to estimate:

- Peak flows at culverts,
- Catch basins, and
- Key city storm water outfall locations.

We investigated what is required to develop a prototype drainage plan for Utqiagvik following standard USACE protocols and software.

Key data utilized for the drainage analysis, based on typical USACE type drainage modeling is shown below. For example, items number 4,5,7, and 9 do not neatly fall into typical drainage plan inputs. Of these “layers” soils, vegetation types, impervious areas are difficult to map or assess in an arctic landscape like Utqiagvik, and will take further research. See Figure 12 below for a graphic showing current arctic Alaska permafrost changes reflective of this unique environment in Utqiagvik.

1. DEM (from LiDAR)
2. Soil mapping / USDA
3. Landcover
4. Vegetation Types
5. Impervious areas Pavement/Buildings/Roof areas
6. Barren/Gravel Areas
7. Wetlands
8. Waterbodies
9. Precipitation data/Prisim/NOAA Atlas 14
10. Existing culvert and storm drain locations

5.1.1 Stream Bed and Watercourse Locations

Since established drainage patterns are disrupted by road construction, it is important to know the locations of existing streams, particularly for the design of new channels and structures to accommodate their flows. For existing transportation facilities, the location of both natural and created channels is necessary to determine drainage patterns. Figures 7 and 8 below show the topography of the “core” Utqiagviak area in relation to the main infrastructure, namely the “utilidor” – a subsurface sewer and water system developed at great expense to the NSB. Figure 8 showing the utilidor on top of a hydro-enforced Hillshade provided by QSI.

Streambed locations were delineated for each surface terrain model using Spatial Analyst and Global Mapper. The accuracy and reasonableness of streambed locations from the surface terrain models were verified by identifying stream patterns using the intensity imagery with supplemental help from Esri imagery. In addition, stream location with respect to known culvert locations and the roads was reviewed. Figure 7 above shows approximate streambed or watercourse lines and basins using the Pilot data along with Esri imagery.

The streambed locations (drainage channels) produced from the LiDAR-based elevation grid appeared proximate (at varying levels of accuracy) to streams identifiable from the aerial images and known drainage structure locations. The stream coverage was also fairly dense, as a result of the relatively small drainage areas defined, but lacked curvilinear detail. Both intermittent channels as well as continually flowing streams appeared to be represented. Locations of possible drainage and base inundation parallel to the roadway were also visible. These locations could represent locations of potential base failure and, in turn, increased road surface deterioration.

Stream placement is not without spatial inaccuracies. The flat terrain makes it difficult to map with exacting precision stream or water courses. A possible explanation for these occurrences is sensitivity to subtle terrain changes and errors. Furthermore, in areas of roadway fill the natural terrain provides no path for stream flow except for parallel to the roadway or terminating at the roadway. In these instances, the roadway essentially acts as a dike.

With the addition of the culvert locations to the LiDAR elevation grid, the alignments of natural streams appeared more accurate and detailed (meandering and curvilinear), again indicating sensitivity to subtle terrain changes. Inclusion of culverts appeared to supplement/enhance roadway cross-section information at locations where LiDAR may not be able to collect all terrain surfaces, e.g., ditch fore slope, bottom, and back slope. At approximately half of the culvert locations, the stream alignment was improved to the point that the stream now flowed through the culvert. Stream alignment also improved upstream from the culvert location, better mirroring the streams visible in the aerial imagery and LiDAR intensity imagery.

LIDAR helps analyze drainage by developing catchment basins and drainage networks. See Figure 10 below. In the Utqiagvik area, it is not uncommon to see topography changes of less than 3 feet on the mile. It is sometimes difficult to see the natural direction that water wants to flow (if it wants to flow at all). Before modern roads and drains were built, this land was generally wet. Because of all the roads and drains, water may no longer take a natural path to the nearest water course. Figure 10 shows water basins or catchment basins delineated using the 2018 LiDAR data. The green points shown on Figure 10 are pour points we identified using the drainage network as a guide. Figure 11 shows LiDAR generated water drainage lines on tundra. This tundra is affected by climate change effects (see Figure 12), so it is not clear how much of the drainage actually penetrates subsurface into the permafrost.

Figure 8. Core Area of Utqiagvik showing utilidor

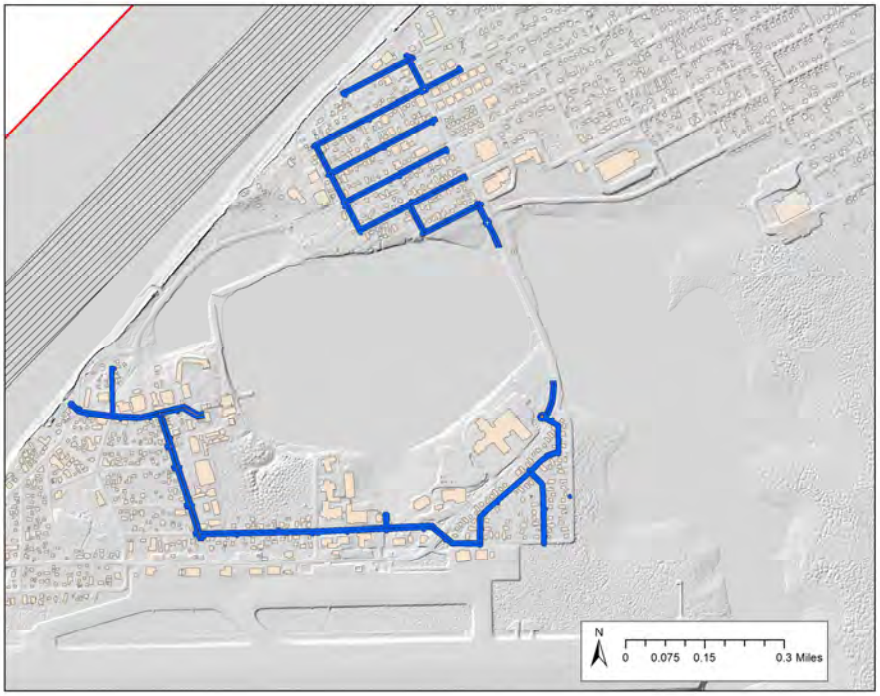


Figure 9. Core Area View with DEM

Figure 10. Flow Line Networks and Catchment Basins in Utqiagvik area

Figure 11. LiDAR generated drainage lines in Utqiagvik

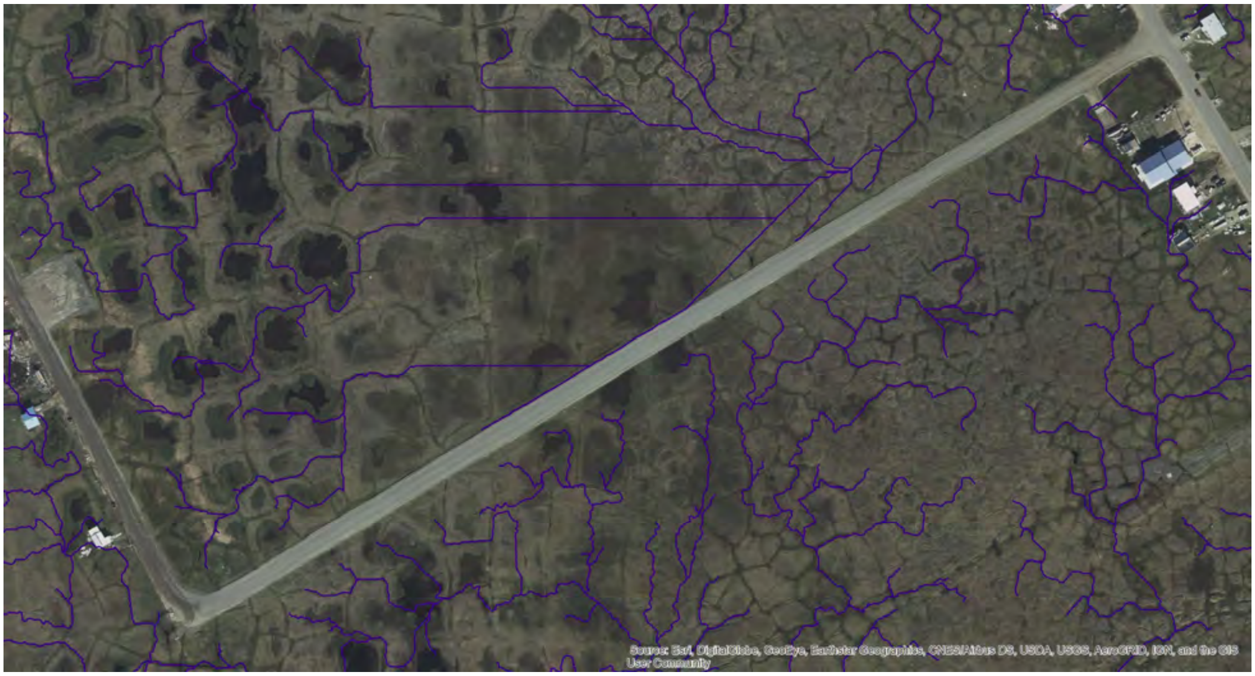
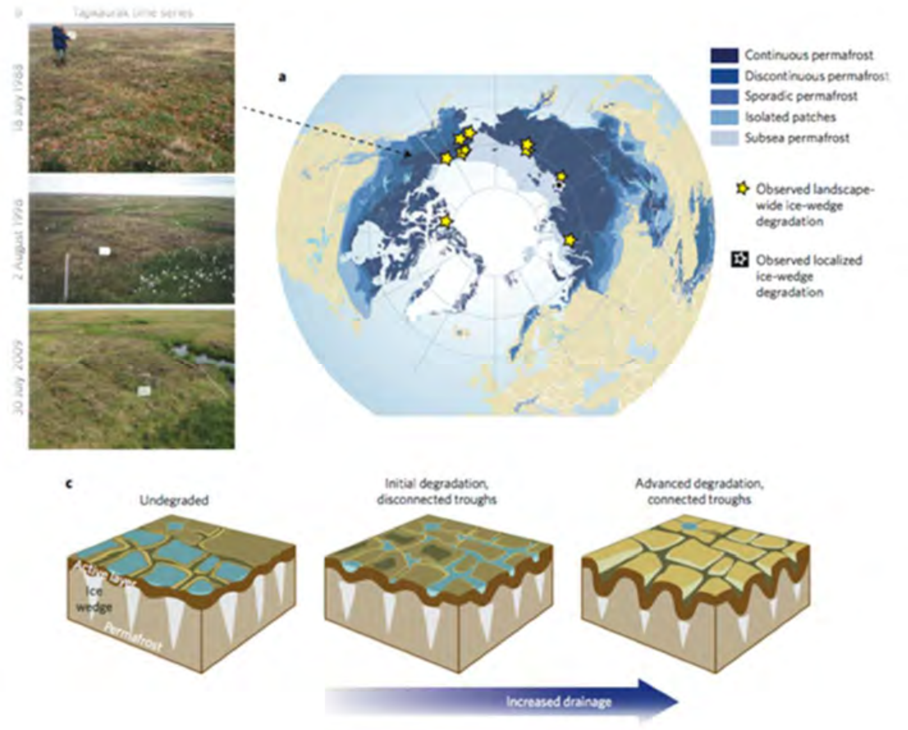

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 12. Permafrost changes in the arctic-effects on drainage (Liljedahl)



5.2 Review of USGS/QSI Pilot Project Datasets

It is not the main purpose of this study to review in detail the USGS/NSB LiDAR data. However, the following systematic approach was used for performing a preliminary and qualitative assessment of the Pilot LiDAR data delivery. Please note, data *acquisition* methods and parameters were not assessed in this study. See the QSI/USGS reports for detail on that aspect of the project.

- Delivery was generally reviewed for completeness of content, and organization
- Projection (coordinate system, etc.) of data was verified
- Best-available imagery was referenced to facilitate data review
- Performed coverage/gap check to ensure proper coverage of the tiles submitted
- Reviewed a QSI statistical analysis of delivery
- Verified that tile naming and metadata conventions were followed
- Verified that deliverable formats were correct
- checked for errors in profile mode (noise, high and low points), mainly using ground.
- Reviewed hydo-breakline data for accuracy and completeness

5.2.1 Tiling Scheme

QSI used a regular tiling scheme to subset the LiDAR data. It was done generating a fishnet measuring 1500 x 1500'. This appears to be a good scaling choice. Perhaps a 2000 x 2000' net would reduce the number of tiles while satisfying file size considerations.

5.2.2 Voids and Completeness of Data

Void/gap check on the AOI. Intensity image is overlaid onto a colored background (in this case red) to allow thorough identification of gross gaps and voids. Mosaics are in Esri grid and .img format. Complete, no breaks. Figure 6 above depicts the area of the mosaicked data.

5.2.3 Hillshades and other Derivatives

In general, the hillshades are well produced and do not appear to have any errors. Intensity imagery mosaic shows good resolution and completeness. See Figure 14 below.

5.2.4 Hydro-Enforced Data

Generally hydro-enforcement in the Pilot appears to be very well defined, as a reflection of well defined hydro breaklines; and adheres to USGS LiDAR Base Specification. Questionable waterbodies and stream course continuity in some places. Lakes look OK. Some drainages are not captured apparently due to the USGS Base Spec 30 meter limit.

5.2.5 Building Footprints

Generally footprints are defined well, and match intensity imagery and other imagery (e.g. Esri online). There are a few places where the automation routine did not capture a real building outline. See Figure 13 below.

Figure 13. Building Footprint issue

5.2.6 Survey Control

QSI acquired 21 control points in the Pilot Area, and these were selected to conform to USGS requirements, namely corresponding to classification per the USGS Base Specification (see References). KE did not assess the location of these points nor methods, but given the results of data quality, appear to be sufficient.

5.2.7 LAS Classification and Filtering

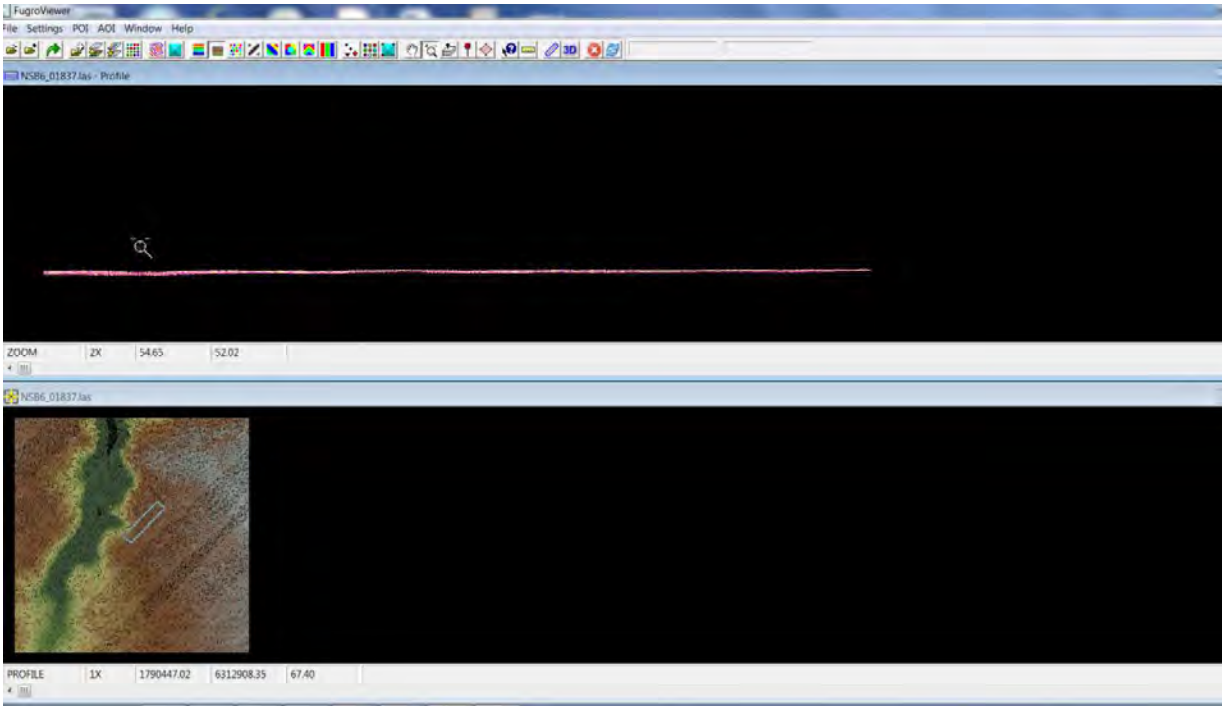
Figure 15 below shows the entire point cloud for the Pilot area; and Figure 14 below shows an example profiling of the bare earth raster, which shows a “clean” surface, i.e. no artifact points above or below the ground line. Profiles like this were taken throughout the Pilot area to check the quality of the filtering, especially the bare earth surface. Profiles were also drawn in Pilot LAS tile (with ground surface checked) to check filtering quality. Other derivatives such as intensity imagery were reviewed for quality (see Figure 16 below).

5.2.8 Metadata

The project metadata was reviewed and checked using the following methods:

Structure of the metadata file was compared against FGDC standards by using the USGS Geospatial Metadata Validation Service for Metadata content including Tile names, Place names, Contact information, and Source time period.

Figure 14. Bare Earth Surface Review



ZOOM 2X 54.65 52.02

PROFILE 1X 1790447.02 6312908.35 67.40

Figure 15. Utqiagvik Pilot Point Cloud Data

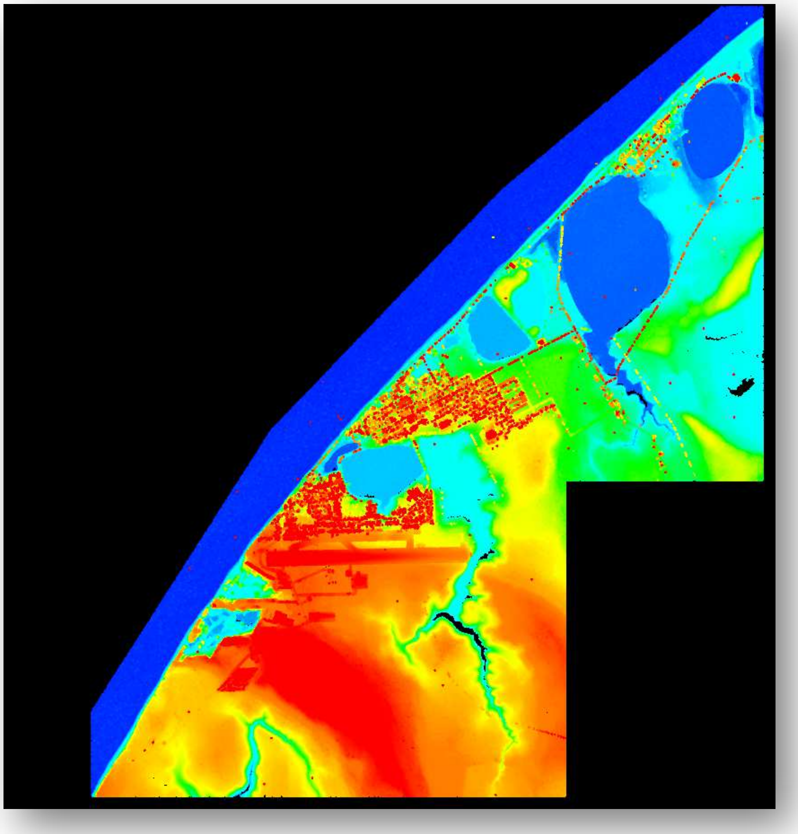


Figure 16. Pilot area LiDAR intensity imagery

6 Software Used in the Pilot Assessment

The main software programs used by KE in performing the qualitative assessment fall into these broad categories. *Note, we will review in more depth choices of 3rd party programs in Task 3.*

- **GIS:** The GIS software platform used by the NSB is Esri's ArcGIS. The NSB utilizes the ArcGIS desktop suite, and Portal for its online data distribution and access by NSB departments. Key ArcGIS tools (extensions) we utilize are Spatial Analyst. 3D Analyst was not used in this Pilot project, but is a nice to have for 3D visualizations, profiling.
- **CAD**: NSB departments and contractors typically use AutoCAD and AutoCAD Civil3D. Civil3D now works with native .LAS files and certain DEM and DTM file formats.

Specialty LiDAR software we reviewed, and used for this analysis, are as follows. Note, in Task 3 we plan on more review and assessment of these programs.

LP360®

A product of GeoCue, it is a geospatial data/process management system especially suited to managing large LiDAR data sets.

MARS 2018®, a Merrick and Company product, designed primarily to process LiDAR data.

QT Modeler® v.8.x: A useful tool for processing, review, and visualization.

For application specific *hydrologic data* processing with LiDAR, there are a number of free or low cost software programs as follows. We did not utilize these programs in this study, but these programs appear to offer a valuable set of tools for expanded hydrological analysis.

- TauDEM (Terrain Analysis Using Digital Elevation Models) is a suite of Digital Elevation Model (DEM) tools for the extraction and analysis of hydrologic information from topography as represented by a DEM. TauDEM was developed with support from the US Army Corps of Engineers, System Wide Water Resources Program.
- ArcHydro: A free extension to ArcGIS developed by David Maidment of the University of Texas, Arc Hydro is a set of data models and tools to support geospatial and temporal data analyses. Arc Hydro can be used to delineate and characterize watersheds in raster and vector formats, define and analyze hydro geometric networks, manage time series data, and configure and export data to numerical models.
- Whitebox GAT: The Whitebox GAT project began in 2009 and was conceived as a replacement for the Terrain Analysis System (TAS). Whitebox GAT is intended as an open-source desktop GIS and remote sensing software package for general applications of geospatial analysis and data visualization.

Drainage Modeling:

For drainage modeling and analyses drainage specialists typically use tools such as HEC-RAS, and HEC-HMS, which are software packages developed by the USACE Hydrologic Engineering Center. Both of these have and are increasingly more GIS enabled. Figures 17 and 18 depict examples.

The Geospatial Hydrologic Modeling Extension (HECGeoHMS) utilizes ArcGIS to develop hydrologic modeling inputs. This is used for analysis of digital terrain data and results in drainage paths and watershed boundaries used to develop a hydrologic data structure representing the watershed response to precipitation.

Figure 17. HEC-HMS Example

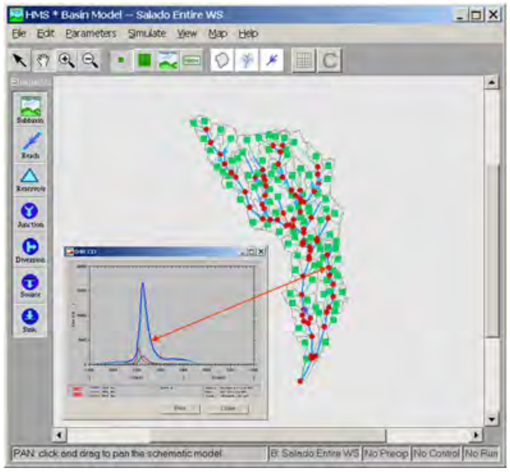
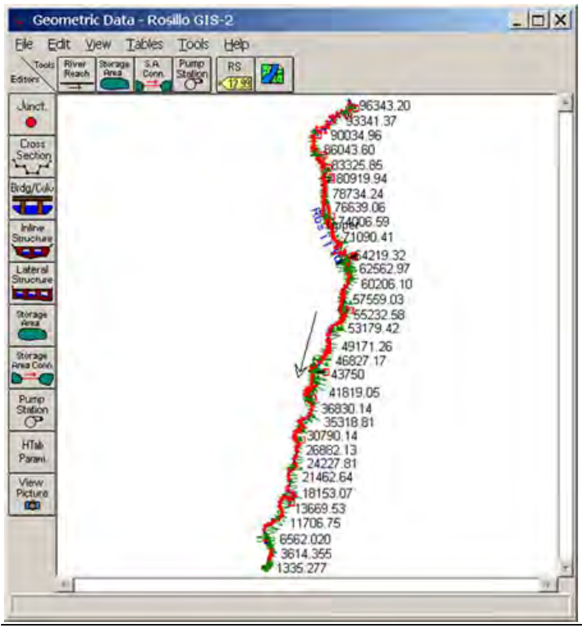


Figure 18. HEC-RAS Example



7 Conclusions and Discussion

This report is an independent assessment sponsored by the NSB of the 2018 LiDAR data, and not to replace the forthcoming analyses that will be done by the USGS of the USGS/NSB LiDAR project data. This report is a qualitative and quantitative assessment conducted by Kinney Engineering performed at this time given the need to as quickly as possible assess the application of this data to NSB needs. It can't be emphasized enough that the 2018LiDAR data provides the NSB with a rich data source for many applications beyond the drainage and flood aspects as focused on here.

We are pleased that the USGS accommodated a QL1 resolution in the 2018 NSB/USGS project. Having the benefit of QL1 became apparent in our mapping of the flat terrain and nuanced tundra landscape of the area. Very few problems in general were found with the USGS/NSB/QSI Pilot dataset. In general, it is a "clean" and high-quality dataset. A non-systematic problem was found during the detailed check of the LAS classified point cloud files. The check found a handful of LAS files that contained what appeared to be a few above-ground artifacts, but this is understandable given this is a preliminary dataset. A non-systematic problem was found during the detailed check of the 3d hydro-lines. The check found a handful of tiles that had ground or water point misclassifications. These misclassifications are small in scope, and probably due to the flat, and sometimes hard to discern topography bordering waterbody features.

As a test of applicability to NSB needs, we delineated catchment basins and watersheds using standard GIS approaches, which resulted in interesting and valid results. However, what could be done as a followup is to determine the influence of stream flow through known hydrologic structures, for example culverts and outflow points (e.g. along the coast). There are techniques for analyzing this in GIS and third-party tools such as LP360, such as adjusting the elevation of the grid cells at these locations, approximately the same elevation as the surrounding terrain, but lower than the surrounding pixels so as to force the streams to flow into the culverts. The overall purpose of KE's exercise was to ensure the Pilot data is suitable for this hydrologic and similar work, not to actually produce a drainage plan or flood control/risk map.

For future work with LiDAR data, it is recommended:

1) Establishing a survey control monumentation database that can be used repeatedly for further LiDAR, UAV, and remote sensing acquisitions. The 21 points QSI acquired in 2018 would serve as a starting point. Additional GCPs are recommended using the input of NSB GIS and local surveyors.
2) Flood control risk mapping is a task that can be performed using the 2018 LiDAR data, and based on the NSB/USACE/KE meeting on December 7, 2018, it appears that this type of mapping is needed for Utqiagvik for various projects.
3) The NSB might want to consider using ancillary software programs for specific LiDAR processing, "fine tuning" and filtering of surfaces, exporting data to CAD and GIS, and

generally working with .LAS files to derive custom products. The ancillary tools we recommend at this time are:

- LP360: designed to work seamlessly with ArcGIS. It's interface is easy to use, and appears (as of this date) to contain most of the functionality the NSB GIS would need.
- Blue Marble Global Mapper and LiDAR Module: Global Mapper and its extension LiDAR Module are very reasonably priced, and robust tools for viewing, processing, and manipulating LiDAR data. However, the programs are not designed for consistency with ArcGIS, which is viewed as a detriment in this assessment.
- FME (by Safe Software): A relatively expensive suite of tools, but powerful, and an industry accepted standard for data interoperability and integration. Not necessary for in- house use especially in a small GIS shop such as the NSB.
- For processing and more visualization of the data, Merrick's MARS 2018 and QTM are robust programs designed for processing LiDAR data primarily. Although fast and full of tools, the program's interfaces are not quite consistent with ArcGIS requiring new learning curves.

The next step in NSB LiDAR implementation is training in use of the LiDAR data. In January, 2019 the NSB and KE will develop a training workshop focused on NSB users, and in late February 2019 we will conduct the training workshop in Anchorage and invite other key local government users, as well as external stakeholders such as the USACE.

8 References

ASPRS, 2014, Positional Accuracy Standards for Digital Geospatial Data, Edition 1, Version 1, November, 2014.

Esri, ArcGIS for Desktop Help, 2018, http://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/incorporating-breaklines-with-lidar.htm

Garcia, Val, 2004, Pilot Study: Automated Techniques to Map Headwaters Stream Networks in the Piedmont Ecoregion of North Carolina, Forestry Department, North Carolina State University, Office of Research and Development, Environmental Protection Agency.

Kinney Engineering/NSB Presentations in 2018 regarding the NSB/USGS LiDAR Project: 12/6/18 PowerPoint, and 12/7/18 PowerPoint at meetings with Alaska DNR (ASTAR and DGGS), Esri, USACE, and the NSB (GIS, Public Works). Meeting on 9/1518 with NSB Jason Bergerson.

Liljedahl Anna K., Julia Boike, Ronald P. Daanen, Alexander N. Fedorov, Gerald V. Frost, Guido Grosse, Larry D. Hinzman,Yoshihiro Iijma, Janet C. Jorgenson, Nadya Matveyeva, Marius Necsoiu, Martha K. Raynolds, Vladimir E. Romanovsky,Jörg Schulla, Ken D. Tape, Donald A. Walker, Cathy J. Wilson, Hironori Yabuki and Donatella Zona, 2016, Pan-Arctic ice-wedge degradation in warming permafrost and its influence on tundra hydrology, Nature Geoscience, Supplementary Information DOI: 10.1038/NGEO2674.

Maune, David F. and Amar Nayegandhi, 2017, Digital Elevation Model Technologies and Applications: The DEM Users Manual, Introduction to the new volume (Vol.3), Coastal GeoTools Conference February 8, 2017. *Note: Volume 3 to be published by ASPRS.*

Oak Ridge National Laboratory, Poppenga, S.K., Worstell, B.B., Danielson, J.J., Brock, J.C., Evans, G.A., and Heidemann, H.K., 2014, Hydrologic enforcement of LiDAR DEMs: U.S. Geological Survey Fact Sheet 2014–3051, 4 p., https://dx.doi.org/10.3133/fs20143051.ISSN 2327-6932 (online),

State of Georgia, 2017, LiDAR Frequently Asked Questions, Georgia State LiDAR Program, Georgia Geospatial Information Office. http://gio.ga.gov/project/enhancing-coastal-resilience-with-green-infrastructure/

State of Vermont and USGS, 2017, Hydro Treatments of LiDAR-Derived DEMS, a PowerPoint presentation. *Note: A good overview of hydro-enforcement of LiDAR data.*

US Army Corps of Engineers, 2007, Alaska Baseline Erosion Assessment, Erosion Information Paper - Utqiagvik, Alaska.

USGS, National Geospatial Program, 2018, Hans Karl Heideman, LiDAR base specification Techniques and Methods 11-B4, February, 2018.

Appendix A. Definition of Technical Terms

3D Elevation Program (3DEP): 3DEP is a cooperative activity with a primary goal to collect nationwide Quality Level 2LiDAR data, with Quality Level 5 IfSAR data in Alaska, over an 8-year period. 3DEP is backed by a comprehensive study which conservatively estimates that elevation data provides new benefits of $690 million per year with the potential to generate $13 billion per year in new benefits through applications that span the economy. Federal funds to support this opportunity were provided by the USGS, the Federal Emergency Management Agency, and the Natural Resources Conservation Service. The USGS is acting in a management role to facilitate planning and acquisition for the broader community through the use of government contracts and partnership agreements. This data collection of the 3DEP consists of LiDAR Point Cloud (LPC) projects as provided to the USGS. These point cloud files contain all the originalLiDAR points collected, with the original spatial reference and units preserved. These data may have been used as the source of updates to the 1/3-arcsecond, 1-arcsecond, and 2-arcsecond seamless 3DEP Digital Elevation Models (DEMs). The 3DEP data holdings serve as the elevation layer of The National Map, and provide foundational elevation information for earth science studies and mapping applications in the United States. LiDAR discrete-return point cloud data are available in the American Society for Photogrammetry and Remote Sensing (ASPRS) LAS format. The LAS format is a standardized binary format for storing 3-dimensional point cloud data and point attributes along with header information and variable length records specific to the data. Millions of data points are stored as a 3-dimensional data cloud as a series of geo-referenced x, y coordinates and z (elevation), as well as other attributes for each point. A few older projects in this collection are in ASCII format. Please refer to http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html for additional information on the .LAS file format. All 3DEP products are public domain.

Aerial photography: A series of photographic images of the ground, taken at regular intervals from an airborne craft, such as an airplane.

American Society of Photogrammetry and Remote Sensing (ASPRS): A scientific association of specialists in the arts of imagery exploitation and photographic cartography.

Area of Interest (AOI): A spatial area identified by one or more communities and/or other stakeholders where there is interest in acquiring imagery and/or LiDAR data.

Breaklines: Traditionally, breaklines were used in surface models to represent all kinds of linear features. With LiDAR, they are mostly used for hydro enforcement. The higher resolution the LiDAR, the less need for breaklines unless the application is water related. Breaklines are important for maintaining the definition of water-related features in an elevation model. Breaklines are used to capture linear discontinuities in the surface, lake shorelines, single-line drains for small rivers, and double-line drains for large rivers. Sometimes, breaklines are also collected to help define and sculpt the surface without necessarily representing discontinuities. Examples of these applications include contour-like form lines and the crests of rounded ridges.

Broad Agency Announcement (BAA): A publicly accessible process to develop partnerships for the collection of LiDAR data for 3DEP. The BAA for the USGS 3DEP was issued on August 16, 2017. (Fed Biz Opps G17PS00746 and Grants.gov G17AS00116).

Catchment Basin: A topographic region in which all water drains to a common outlet.

Digital Elevation Model (DEM): A digital cartographic representation of the elevation of the land at regularly spaced intervals in x and y directions, using z values referenced to a common vertical datum.

Digital Terrain Model (DTM): A vector dataset composed of 3D breaklines and regularly spaced 3D mass points, typically created through stereo photogrammetry, that characterize the shape of the bare-earth terrain. Breaklines differentiate a DTM from a DEM as they more precisely delineate linear features whose shape and location would otherwise be lost. A DTM is not a surface model; its component elements are discrete and not continuous; a TIN or DEM surface must be derived from the DTM.

Image Resolution: Describes the linear size that an image pixel or raster cell represents on the ground. Common resolutions are 3 inch, 6 inch, 1 foot, 1 meter, etc.

Geographic Information Systems (GIS): A GIS manages spatial and tabular data in one software system and provides tools to store, retrieve, manage, display, and analyze various types of tabular and geospatial data including aerial imagery,LiDAR, and vector data.

Ground Control Point (GCP): GCPs are typically captured using GPS receivers to survey coordinates of photo-identifiable points on the ground. Coordinates are reported in latitude, longitude, and elevation—or northing, easting, and heights. GCPs are typically collected by surveyors who are physically sent to the location of the required control point. GCPs are used to measure and validate a position relative to photo-identifiable elements nearby, such as concrete sidewalks and buildings.

Ground Sample Distance (GSD): The distance between two consecutive pixel centers measured on the ground. The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details. GSD and pixel are often used interchangeably.

Hydro-enforcement: Hydrologic-enforcement of LiDAR-derived digital elevation models modifies the elevations of artificial impediments (such as road fills or railroad grades) to simulate how man-made drainage structures such as culverts or bridges allow continuous downslope flow.LiDAR-derived DEMs contain an extremely high level of topographic detail; thus, hydro-enforced LiDAR-derived DEMs are essential to the U.S. Geological Survey (USGS) for complex modeling of riverine flow. The USGS Coastal and Marine Geology Program (CMGP) is integrating hydro-enforced LiDAR-derived DEMs (land elevation) and LiDAR-derived bathymetry (water depth) to enhance storm surge modeling in vulnerable coastal zones.

Hydro-flattening: Hydro-flattening is the process of creating a LiDAR-derived DEM in which water surfaces appear / behave as they would in traditional topographic DEMs created from photogrammetric digital terrain models (DTMs). A hydro-flattened DEM is a topographic DEM and should not be confused with hydro-enforced or hydro conditioned DEMs, which represent hydrologic surfaces. A traditional topographic DEM (such as NED) represents the actual ground surface, in which hydrologic features are handled in established ways. Roadways crossing drainages / passing through culverts remain in the surface model because they are part of the landscape. This is because the culvert beneath the road is the man-made feature. In addition, bridges and other man-made structures above the landscape are removed.

Interferometric Synthetic Aperture Radar (IfSAR): A mapping technology acquiring data usually by means of a radar type sensor system mounted on jet aircraft. This radar mapping technology is an effective tool for collecting data under challenging circumstances such as cloud cover, extreme weather conditions, rugged terrain, and remote locations. Mapping products are usually in the 1:24,000 scale range, thus the data typically is not used for engineering or detailed local government purposes. The three main products are, Digital Elevation Models (DEMs), digital Orthorectified Radar Images (ORRIs), and Topographic Line Maps (TLMs). Maps from iFSAR can be created at scales ranging from 1:10,000 to 1:50,000. The State of Alaska SDMI program is utilizing IfSAR to develop a new basemap for the entire state of Alaska.

LAS File: An industry-standard binary format for storing airborne LiDAR data endorsed and a standard used by the ASPRS and USGS. The LAS dataset allows for examination of LAS files in mapping and LiDAR software, in their native format, quickly and easily, providing detailed statistics and area coverage of the LiDAR data contained in the LAS files. Originally,LiDAR data was only delivered in ASCII format. With the massive size of LiDAR data collections, a binary format called LAS was soon adopted to manage and standardize the way in which LiDAR data was organized and disseminated. Now it is quite common to see LiDAR data represented in LAS. LAS is a more acceptable file format, because LAS files contain more information and, being binary, can be read by software programs more efficiently. LAS is a published standard file format for the interchange of LiDAR data. It maintains specific information related to LiDAR data, and stores the data in classified descriptions. It is a way for vendors and clients to interchange data and maintain all information specific to that data. Each LAS file contains metadata of theLiDAR survey in a header block followed by individual records for each laser pulse recorded. The header portion of each LAS file holds attribute information on the LiDAR survey itself: data extents, flight date, flight time, number of point records, number of points by return, any applied data offset, and any applied scale factor. The following LiDAR point attributes are maintained for each laser pulse of a LAS file: x,y,z location information, GPS time stamp, intensity, return number, number of returns, point classification values, scan angle, additional RGB values, scan direction, edge of flight line, user data, point source ID and waveform information.

Light Imaging, Detection, And Ranging (LiDAR): A technology that uses a sensor to measure distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse's reflection(s). The measured time interval for each reflection is converted to distance, which when combined with position and attitude information from GPS, IMU, and the instrument itself, allows the derivation of the 3D-point location of the reflecting target's location.

National Agriculture Imagery Program (NAIP): A program to acquire aerial imagery at one-meter pixel resolution during the agricultural growing seasons, mostly in the continental U.S.

Orthoimagery Mosaic: A single image mosaic of multiple raw imagery tiles or files. The orthomosaic process will generate a georeferenced image mosaic and optionally a digital surface model in various different formats.

Orthorectification: The process of correcting the geometry of an image so that it appears as though each pixel were acquired from directly overhead. The topographical variations in the surface of the earth and the tilt of the satellite or aerial sensor affect the distance with which features on the satellite or aerial image are displayed. The more topographically diverse the landscape, the more distortion inherent in the image.

Orthophotographs: Aerial photographs geometrically corrected to create uniform scale and to remove displacements caused by terrain relief, sensor distortion, and camera tilt.

Point Cloud: One of the fundamental types of geospatial data (others being vector and raster), a point cloud is a large set of three dimensional points, typically from a LiDAR collection.

Quality Level: The LiDAR community including the USGS, has been gradually adopting the terminology "Quality Level" to categorize airborne LiDAR data. The idea is to use a simple scheme to characterize the more important features of a LiDAR data set into a few broad groups designated QLn where n is the quality level. There are two major criteria in the Quality Level rating: point density and vertical accuracy. Point density is simply the average number of points per unit area. I like to use meters regardless of the horizontal units of the data and thus tend to characterize this as points per square meter (ppm2). Another way of looking at this criteria is the average distance between points, the nominal point spacing (NPS). In practice, NPS is difficult to measure because LiDAR point spacing is inherently non-uniform. The second significant criteria is the vertical accuracy. This is expressed as the root mean square error (RMSE). It is a measure of the absolute (as in absolute value) deviation of the data from some known vertical datum, usually surveyed ground locations.

QUALITY LEVEL (QL)	DENSITY (PTS/M2)	PRECISION (RMSE ≤ CM)	SWATH OVERLAP DIFFERENCE (RMSE ≤ CM)
QL0	8	3	4
QL1	8	6	8
QL2	8	12	8
QL3	0.5	12	16

Raster Data: One of the fundamental types of geospatial data (others being vector and point cloud), a raster is an array of cells (or pixels) that each contain a single piece of numeric information representative of the area covered by the cell.

Remote Sensing: The technology of acquiring multi-spectral information about the earth's surface and atmosphere using sensors mounted on airborne platform (planes, helicopter) or satellites.

Satellite images: Images taken from satellites, which orbit the earth at much higher altitudes than airplanes. Satellites use a variety of methods to produce images, including infrared, water vapor, and visible image technologies. Satellite imagery resolution varies from 30- centimeter pixel to 5 meter plus pixel in the commercial market.

Vector Data: One of the fundamental types of geospatial data (others being raster and point cloud), vectors include a variety of data structures that are geometrically described by x and y coordinates, and potentially z values. Vector data subtypes include points, lines, and polygons.

Appendix B. QSI 2018 Pilot Deliverables and Report on Utqiagvik Pilot Data

quantum SPATIAL

Quantum Spatial, Inc. – 1100 Circle Blvd., NE, Ste. 126, Corvallis, OR 97330 – Ph. 541-752-1204 - www.quantumspatial.com

20 November 2018

Jayna Winehouse
USGS NGTOC
1400 Independence Rd. MS547
Rolla, MO 65401

Dear Jayna,

Enclosed is the selected pilot LiDAR dataset from the USGS North Slope Borough Communities, Alaska 3DEP LiDAR project. This pilot site was carefully selected and approved by the United States Geological Survey in order to assess accuracy within the project area. The USGS North Slope Borough Communities LiDAR acquisition occurred between September 7th, 2018 and September 11th, 2018.

This pilot dataset is projected in Alaska State Plane Zone 6, the horizontal datum is NAD83 (2011), and the vertical datum is NAVD88, Geoid12B. Horizontal and vertical units are in US survey feet. Additional delivery areas will be projected into Alaska State Plane Zones; 2, 4, 7 and 8.

While US survey feet are commonly used units within the Alaska State Plane projection, there is no corresponding EPSG or GeoTiff code; the US foot version of this projection does not have a formal statutory definition. To remain in compliance with contract specifications of including Well Known Text within the LAS header, the EPSG code has been stripped from the projection with the false easting/northing modified to match US foot as the provided units and the projection name modified to match the OGC standard. Please let us know if you have questions or comments on this decision.

Accuracy statistics for the dataset have been provided below. We encourage you to review this data and respond with any questions you may have; however, a report detailing density results, ground and airborne survey, and processing information for the project area will be provided with the final delivery.

Files enclosed include:

1. LAS v. 1.4 LiDAR point cloud data:
    - All Classified Returns delineated in 1500 x 1500 foot tiles
2. 1.5 Foot ESRI Grids
    - Hydroflattened Bare Earth Digital Elevation Model (DEM), Mosaic
    - Hydroflattened Bare Earth Digital Elevation Model (DEM), delineated in 1500 x1500 foot tiles
    - Hydroflattened Bare Earth Shaded Relief Raster (Hillshade), Mosaic
    - Hydroflattened Bare Earth Shaded Relief Raster (Hillshade), delineated in 1500 x1500 foot tiles
    - Highest Hit Digital Surface Model (DSM), Mosaic
    - Highest Hit Digital Surface Model (DSM), delineated in 1500 x1500 foot tiles
    - Highest Hit Shaded Relief Raster (Hillshade), Mosaic
    - Highest Hit Shaded Relief Raster (Hillshade), delineated in 1500 x1500 foot tiles
3. 1.5 Foot Imagine (*.IMG) files
    - Hydroflattened Bare Earth Digital Elevation Model (DEM), Mosaic
    - Hydroflattened Bare Earth Digital Elevation Model (DEM), delineated in 1500 x1500 foot tiles
    - Hydroflattened Bare Earth Shaded Relief Raster (Hillshade), Mosaic
    - Hydroflattened Bare Earth Shaded Relief Raster (Hillshade), delineated in 1500 x1500 foot tiles
    - Highest Hit Digital Surface Model (DSM), Mosaic
    - Highest Hit Digital Surface Model (DSM), delineated in 1500 x1500 foot tiles
    - Highest Hit Shaded Relief Raster (Hillshade), Mosaic
    - Highest Hit Shaded Relief Raster (Hillshade), delineated in 1500 x1500 foot tiles
4. 1.5 Foot GeoTIFFs (*.tif)
    - Intensity Image, Mosaic
    - Intensity Images, delineated in 1500 x 1500 foot tiles
5. Vector Shapefiles (*.shp)
    - LiDAR Pilot Boundary
    - LiDAR Full Boundary for Zone 6 AOIs
    - Pilot Tile Index
    - Full Tile Index for Zone 6 AOIs
    - Pilot Flightline Index
    - Pilot Flightline Total Area Covered Index
    - 2 ft. Contours, delineated in 1500 x 1500 foot tiles.
    - 3D Waters Edge Breaklines
    - 2D Building Footprint
    - Ground Survey Monuments
    - Supplemental Ground Control Points
    - Vegetated Vertical Accuracy Check Points
    - Non-Vegetated Vertical Accuracy Check Points

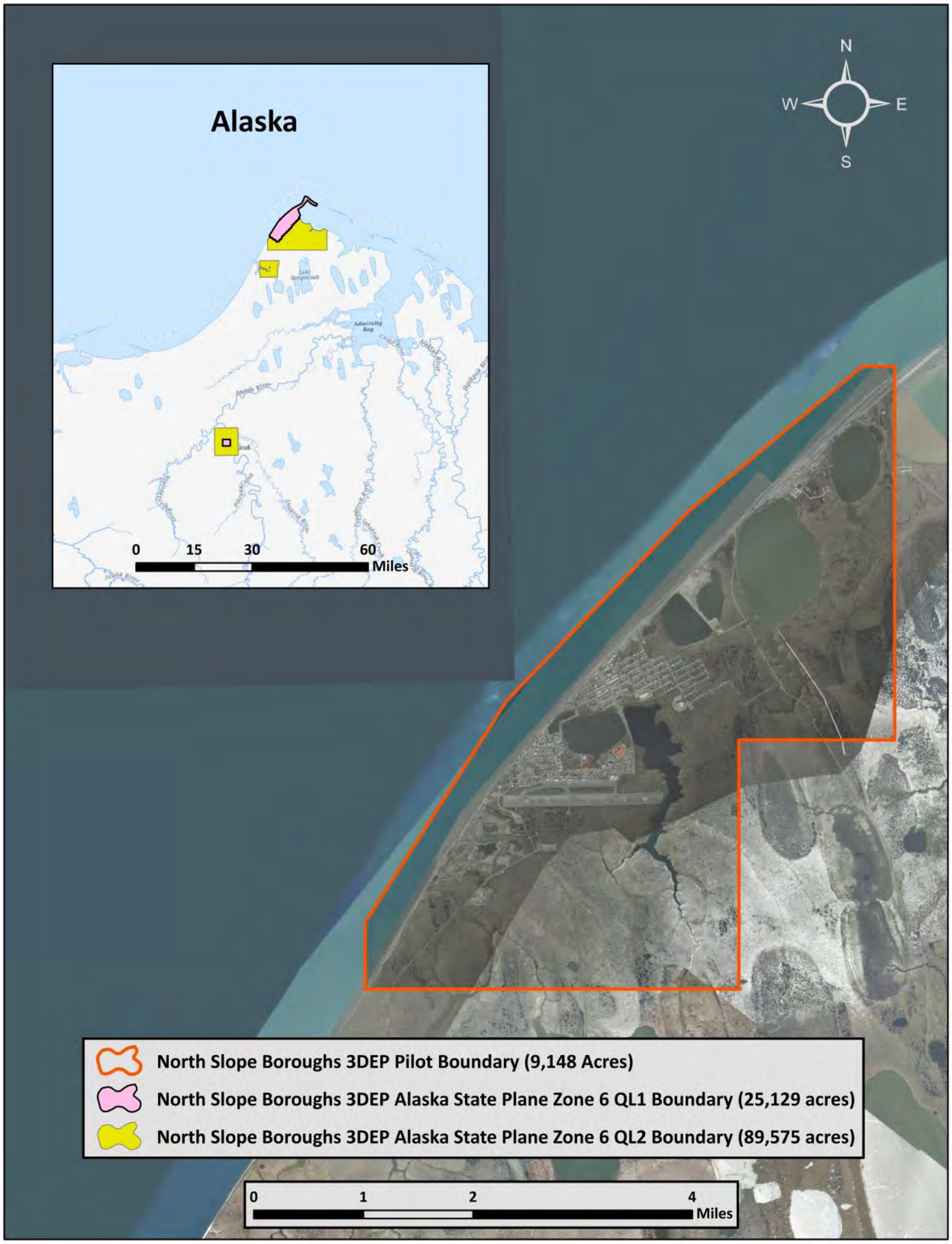


Figure 1: Location map of the North Slope Boroughs 3DEP Pilot Site

LiDAR Accuracy Assessments

The accuracy of the LiDAR data collection can be described in terms of vertical accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself).

LiDAR Absolute Vertical Accuracy

Absolute accuracy was assessed using Non-Vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy[1]. NVA compares known ground quality assurance point data collected on open, bare earth surfaces with level slope (<20°) to the unclassified point cloud, as well as the raster bare earth surface generated by the LiDAR points (Table 1). NVA is a measure of the accuracy of LiDAR point data in open areas where the LiDAR system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval (1.96 * RMSE).

The mean and standard deviation (sigma σ) of divergence of the ground surface model from quality assurance point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics. For the North Slope Borough survey, 56 quality assurance points were collected by Dowl Engineering and Umiaq Environmental, LLC . 21 of these points were located in the Pilot Area resulting in a non-vegetated vertical accuracy of 0.147 feet as compared to the North Slope Boroughs 3DEP bare earth DEM, and 0.143 feet as compared to the unclassified point cloud (Figure 2, Figure 3).

QSI also assessed absolute accuracy using 3 ground control points. Although these points were used in the calibration and post-processing of the LiDAR point cloud, they still provide a good indication of the overall accuracy of the LiDAR dataset, and therefore have been provided in Table 1 and Figure 4**.**

---

[1] Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014. http://www.asprs.org/PAD-Division/ASPRS-POSITIONAL-ACCURACY-STANDARDS-FOR-DIGITAL-GEOSPATIAL-DATA.html.

Table 1: Absolute accuracy results

	Absolute Accuracy		
	Quality Assurance Points (NVA), as compared to Bare Earth DEM	**Quality Assurance Points (NVA), as compared unclassified LAS**	**Ground Control Points**
Sample	21 points	21 points	3 points
NVA (1.96*RMSE)	0.147 ft 0.045 m	0.143 ft 0.044 m	0.147 ft 0.045 m
Average	0.030 ft 0.009 m	-0.006 ft -0.002 m	-0.013 ft -0.004 m
Median	0.036 ft 0.011 m	-0.013 ft -0.004 m	-0.023 ft -0.007 m
RMSE	0.075 ft 0.023 m	0.073 ft 0.022 m	0.075 ft 0.023 m
Standard Deviation (1σ)	0.071 ft 0.021 m	0.074 ft 0.023 m	0.091 ft 0.028 m

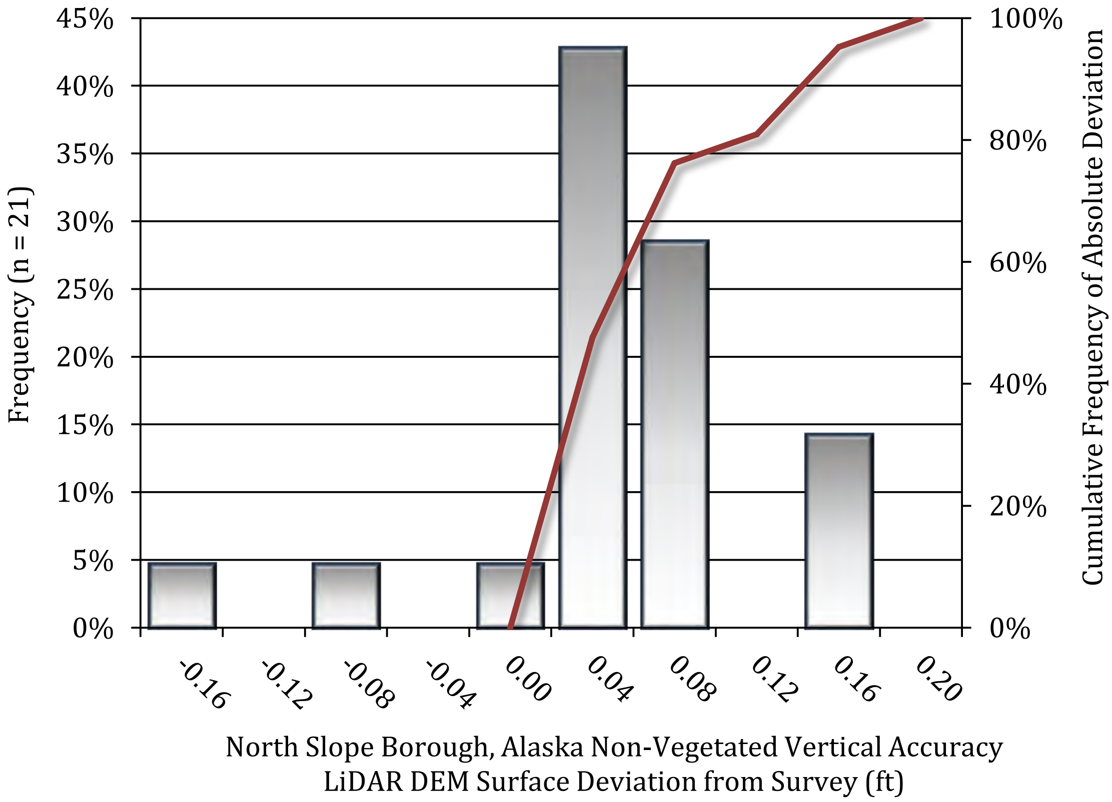


Figure 2: Frequency histogram for LiDAR derived surface deviation from non-vegetated quality assurance point values

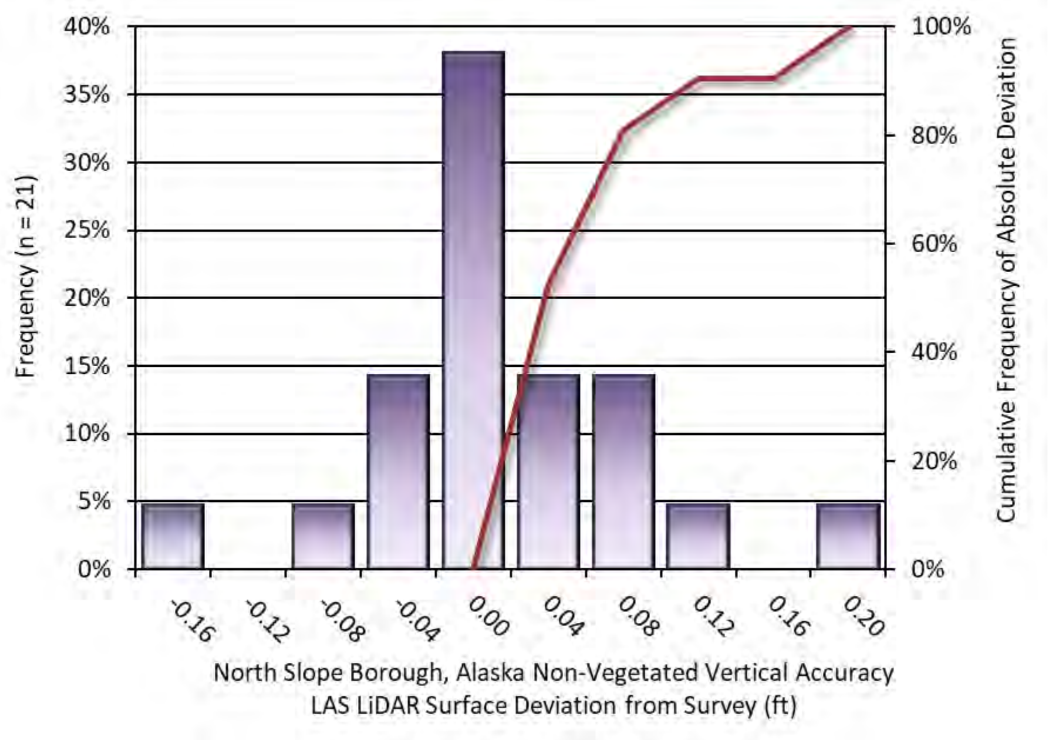


Figure 3: Frequency histogram for LiDAR unclassified point deviation from non-vegetated quality assurance point values

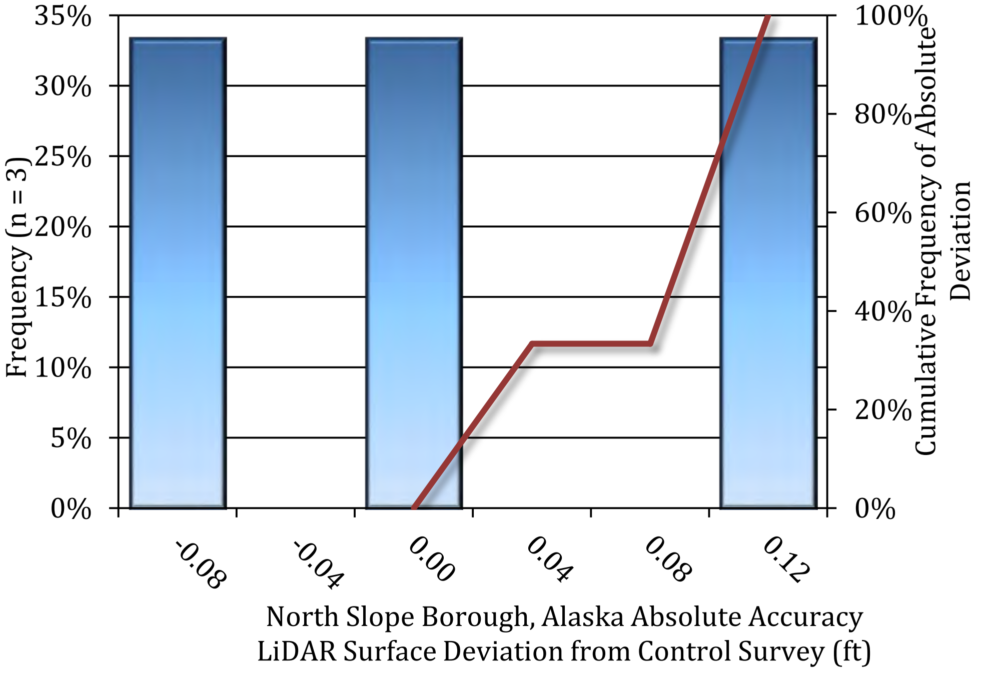


Figure 4: Frequency histogram for LiDAR surface deviation from ground control point values

LiDAR Vegetated Vertical Accuracy

QSI also assessed vertical accuracy using Vegetated Vertical Accuracy (VVA) reporting. VVA compares known ground quality assurance point data collected over vegetated surfaces using land class descriptions to the raster bare earth surface generated by the ground classified LiDAR points. VVA is evaluated at the 95th percentile (Table 2, Figure 5).

Table 2: Absolute accuracy results

Absolute Vertical Accuracy	
	Vegetated Vertical Accuracy (VVA)
Sample	5 Points
95th Percentile	0.328 ft 0.100 m
Average	-0.128 ft -0.039 m
Median	-0.236 ft -0.072 m
RMSE	0.234 ft 0.071 m
Standard Deviation (1σ)	0.218 ft 0.067 m
95% Confidence (1.96*RMSE)	0.458 ft 0.140 m

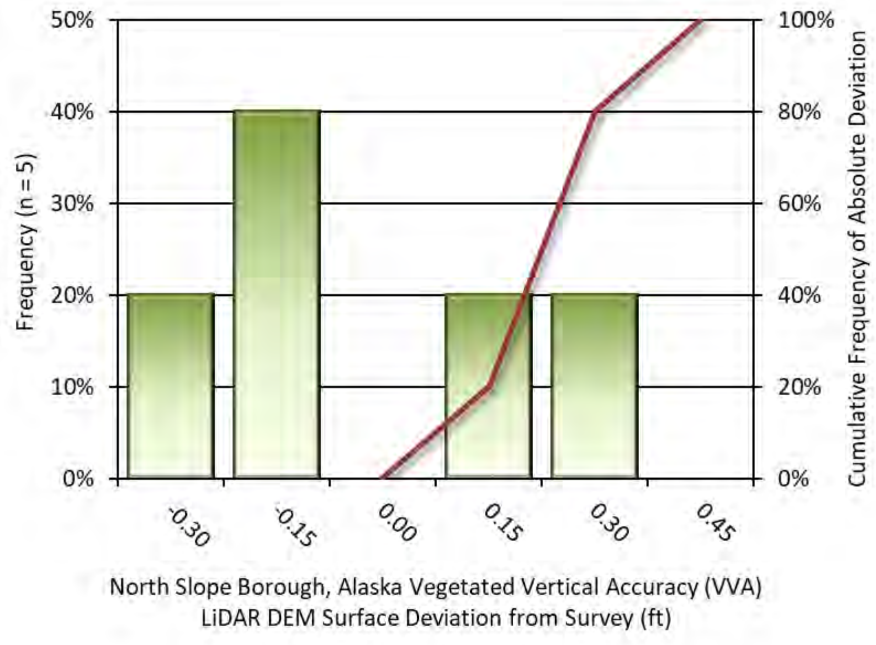


Figure 5: Frequency histogram for LiDAR derived surface deviation from all land cover class point values (VVA)

LiDAR Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the LiDAR system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the Fairbanks LiDAR project was 0.068 feet (Table 3, Figure 6).

Table 3: Relative accuracy results

Relative Accuracy	
Sample	20 surfaces
Average	0.068 ft 0.021 m
Median	0.066 ft 0.020 m
RMSE	0.067 ft 0.021 m
Standard Deviation (1σ)	0.004 ft 0.001 m
1.96σ	0.008 ft 0.003 m

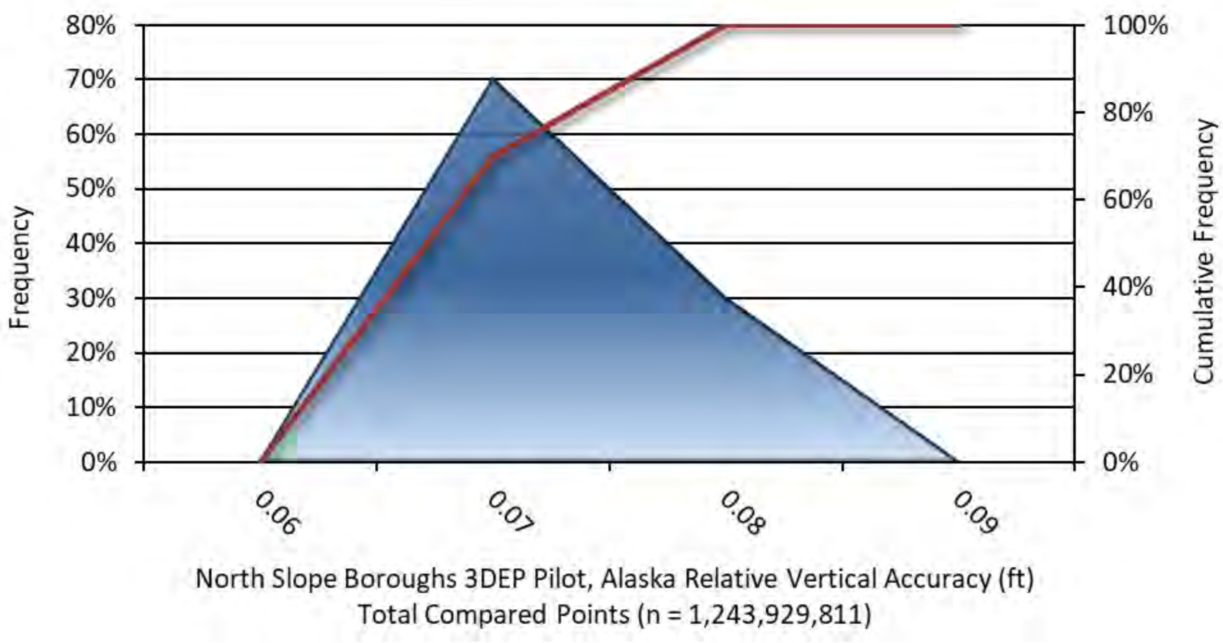


Figure 6: Frequency plot for relative vertical accuracy between flight lines