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Federal Airborne LiDAR Data Acquisition Guideline

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Table of Contents

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Additional Information

For more information about this document, please contact the Canada Centre for Mapping and Earth Observation of Natural Resources Canada: NRCan.Geoinfo.RNCan@Canada.ca.

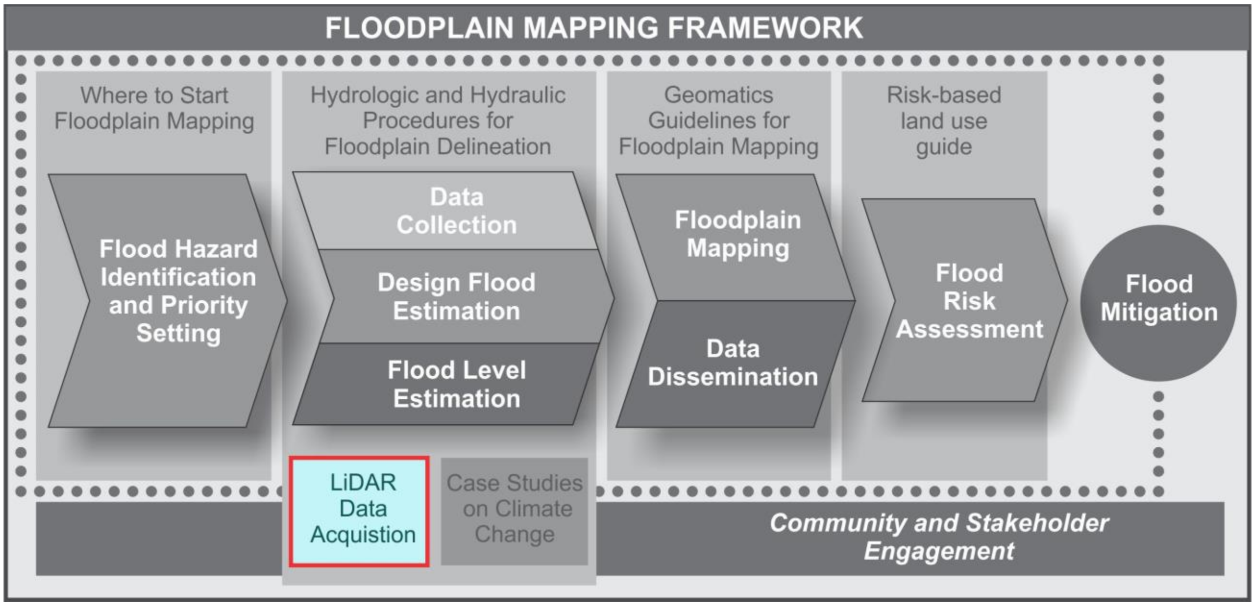
FEDERAL FLOODPLAIN MAPPING GUIDELINES SERIES

The following documents are intended to inform any individual or organization involved with floodplain management in Canada:

1. Federal Floodplain Mapping Framework (2017)
2. Flood Hazard Identification and Priority Setting (*to be developed*)
3. Federal Hydrologic and Hydraulic Procedures for Floodplain Delineation (*2017*)
4. **Federal Airborne LiDAR Data Acquisition Guideline (2017)**
5. Case Studies on Climate Change in Floodplain Mapping (*2017*)
6. Federal Geomatics Guidelines for Floodplain Mapping (*2017*)
7. Flood Risk Assessment (*to be developed*)
8. Risk-based land-use guide: Safe use of land based on hazard risk assessment (2015)
9. Bibliography of Best Practices and References Related to Flood Mitigation (*2017*)

FLOODPLAIN MAPPING FRAMEWORK

The Floodplain Mapping Framework consists of all the components of the flood mitigation process, from flood hazard identification to the implementation of flood mitigation efforts. The following flow chart illustrates the relationship between these different components:



LIST OF ABREVIATIONS AND ACRONYMS

Abbreviation	Description
ANPD	Aggregate Nominal Pulse Density
ANPS	Aggregate Nominal Pulse Spacing
AOI	Area of Interest
ASPRS	American Society of Photogrammetry and Remote Sensing
CHA	Calculated Horizontal Accuracy
CCMEO	Canada Centre for Mapping and Earth Observation
CGG2013	Canadian Geoid 2013
CGVD	Canadian Geodetic Vertical Datum
CORS	Continuously Operating Reference Stations
CQL	Canadian Quality Level
CSRS	Canadian Spatial Reference System
DCAOI	Data collection Area of Interest
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EPSG	European Petroleum Survey Group
ESRI	Environmental Systems Research Institute
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Position System
GRS80	Geodetic Reference System 1980
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ISO	International Standard Organization
LAS	LASer file format exchange
LAZ	LASzip
LiDAR	Light Detection and Ranging
NIR	Near Infrared
NPD	Nominal Pulse Density
NPS	Nominal Pulse Spacing
NRCan	Natural Resources Canada
NTS	National Topographic System
NVA	Non-Vegetation Vertical Assessment
OGC	Open Geospatial Consortium
PDOP	Position Dilution of Precision
PLS	Pulse(s)
PPP	Precise Point Positioning
$RMSE_X$	Horizontal Root Mean Square Error in the *x* direction (easting)
$RMSE_Y$	Horizontal Root Mean Square Error in the *y* direction (northing)

RMSE_R	Horizontal Root Mean Square Error in the radial direction (includes both *x* and *y* directions)
RMSE_Z	Vertical Root Mean Square Error in the *z* direction (elevation)
RMSD_Z	Vertical Root Mean Square Difference in the *z* direction (elevation)
RTK	Real Time Kinematic
SBET	Smooth Best Estimate Trajectory
TIN	Triangular Irregular Network
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VVA	Vegetation Vertical Assessment
WKT	Well Know Text
XML	eXtensible Markup Language

1.0 INTRODUCTION AND PURPOSE

Development of this document has been coordinated by the Canada Centre for Mapping and Earth Observation (CCMEO) within Natural Resources Canada in response to the needs of the geospatial community and the government for a national guideline for acquisition of airborne LiDAR data. A key strategy of the CCMEO is to improve the national elevation data set through consistent application of airborne LiDAR technology. LiDAR has extensively been adopted across Canada by municipalities, provinces, territories and federal government departments as the main technology for acquiring high precision elevation data. The intention of this document is to provide the ***minimum*** specifications to lead towards consistency in airborne LiDAR data acquisition across all levels of government in Canada, as well as to improve international cooperation with the United States along areas of cross-border data collection.

The process for developing the guideline has involved consultation with government, industry and academia, as well as a review of international best practices to provide a broad perspective for establishing the guideline. The federal guideline addresses many complex considerations including data acquisition, processing, validation, and deliverables, with the focus on developing accurate elevation data. The emphasis of the guideline is on data quality and accuracy requirements, while allowing for innovation and future technological advancements. It is the aim of the guideline to accommodate project-specific requirements, and there are cases where the suggested LiDAR acquisition specifications may be relaxed or modified due to factors such as project data requirements and financial considerations. The intent of this guideline is to set a ***minimum*** quality threshold to achieve the federal government needs for unified national elevation data set. The guideline also contains supplemental recommendations for LiDAR acquisition in specific application areas, including forestry, floodplain mapping, mapping of high relief areas, and urban infrastructure.

LiDAR acquisition is an industry heavily reliant on cutting edge technology and is therefore seeing constant improvements in the technological components used in surveys, as well as software and methods used in LiDAR analysis. This document is reflective of the best practices in LiDAR acquisition at the time of the document release. Natural Resources Canada intends to update this document periodically as the industry develops.

2.0 NOTE ON TERMINOLOGY

This guideline contains numerous references to industry specific terms that may vary in other application areas or differ from other guidelines or specifications. For example, in the LiDAR community, bare earth DEM is commonly used to represent ground surface terrain. In this guideline, DTM is used in alignment with the High Resolution Digital Elevation Model (HRDEM) – CanElevation Series - Product Specification Edition 1. DTM is considered equivalent to bare earth DEM. In addition, the term ‘pulse’ is used to represent the transmitted and received laser electromagnetic energy, while ‘point data’ represents pulse data that has been post processed and classified into point cloud. A glossary included in this document provides term definitions in the context of the present guideline.

3.0 TARGET AUDIENCE

This document is part of the Federal Floodplain Mapping Guidelines Series and is to be used as a resource for the acquisition of base elevation data from airborne LiDAR data undertaken across Canada. This guideline aims to provide advice to federal, provincial and territorial departments, whose responsibility is to provide technical guidance to their implementing bodies, as well as individuals and organizations in Canada that need to understand and plan for airborne LiDAR data acquisition. Users of this guideline may include department managers, project coordinators, geomatics experts, water resource engineers, and planners both within and outside of government. The document assumes that users have basic understanding of LiDAR technology and data, including terminology and data structure.

Some provinces and territories have already developed their own guidelines and specifications for airborne LiDAR data acquisition. Hence, this guideline is intended as a basis to further harmonize requirements for acquiring LiDAR data across Canada.

4.0 GUIDELINE STRUCTURE

The guideline has been organized based on a workflow structure involving planning, collection, processing, data validation and expected deliverables of airborne LiDAR data in the context of a Canadian landscape. Information on forest, urban infrastructure, floodplain and high relief mapping applications has been provided in the appendices section of the guideline. Appendices represent current best practice for collection of airborne LiDAR data. Recommended data and collection parameters are provided. In addition, an annex is also included for addressing contract related items for project data collections. The structure of the guideline is referenced by categories as listed below.

1. Planning
2. Acquisition
3. Data Processing
4. Validation
5. Deliverables

5.0 NATIONAL ELEVATION SUMMARY REQUIREMENTS

The Government of Canada's National Elevation Strategy intends to increase high-resolution elevation data coverage for Canada. Airborne LiDAR is a key technology for supporting this strategy. The strategic goal is to develop a national elevation grid at 1 m resolution for the southern portion of Canada (south of the productive forest line). This guideline outlines the requirements for utilizing airborne LiDAR data to meet this goal. The minimum requirements for the acquisition of airborne LiDAR data for a national elevation product are summarized in Table 1 below.

The emphasis of the guideline has been on the data and quality considerations. The requirements have collectively been defined as Canadian Quality Level 1 (CQL1). Future versions of this document may be expanded to include additional CQL's, for example, specific application areas, such as urban infrastructure and floodplain mapping. The rest of the document provides further details on the CQL1 specifications including project planning, data validation and deliverables including recommendations, assumptions and consideration. Users are advised to read the whole document for details on the requirements.

Table 1. Canadian Quality Level 1 (CQL1) Key Summary Requirements for Topographic Base Mapping.

Requirements	**Canadian Quality Level 1 (CQL1)**	**Category**
Pulse Density (ANPD)	≥ 2 pls/m^2	Acquisition
Pulse Spacing (ANPS)	≤ 0.71 m	Acquisition
Vertical Accuracy (NVA)		
Vertical Root Mean Square Error ($RMSE_Z$)	≤ 10.0 cm	Acquisition
Vertical Accuracy – 95% confidence level (≈ 1.96 * $RMSE_Z$)	≤ 19.6 cm	Acquisition
Vertical Accuracy (VVA) – 95th percentile	≤ 29.4 cm	Acquisition
Horizontal Accuracy (FHA)		
Horizontal Root Mean Square Error ($RMSE_R$)	≤ 35.1 cm	Acquisition
Horizontal Accuracy – 95% confidence level (≈ 1.7308 * $RMSE_R$)	≤ 60.0 cm	Acquisition
Calculated Horizontal Accuracy (CHA)	≤ 60.0 cm	Acquisition
Relative Vertical Accuracy		
Intraswath (smooth surface repeatability)	≤ 6 cm	Validation
Interswath (swath overlap difference) – $RMSD_Z$	≤ 8 cm	Validation
Interswath (swath overlap difference) – Maximum difference	± 16 cm	Validation
Horizontal Datum	NAD83 CSRS epoch 2010	Acquisition
Vertical Datum	CGVD2013	Acquisition
Geoid Model	CGG2013	Acquisition
Map Projection	Universal Transverse Mercator	Acquisition

Minimum Swath Overlap	15%	Acquisition
Pulse Returns	Minimum 2 returns (First and Last) Intermediate is optional.	Acquisition
Classification	1 – Processed but unclassified 2 – Ground 9 – Water 7 – Low points (noise) 17 – Bridge decks 18 – High noise	Processing

6.0 GUIDELINE

6.1 Project Planning

Prior to airborne LiDAR data collection, vendors will undertake activities to design an acquisition plan and establish a processing approach to meet the specification as outlined in this document. Key planning tasks are identified in the following sections and will form part of the project deliverables. The following sections outline the type of information that will be assembled into a Project Report.

6.1.1 Project Method

Description

The vendor is required to provide details on the methodology selected meets the technical requirements of the specifications. The project methodology must be described in a project planning report to be submitted in advance of the data collection.

Requirements

Table 2 summarizes key project method requirements.

Table 2. Project method requirements.

Name	Description	Category
Flight Planning	Details on flight coverage, flight line location, overlap, calibration flights, tie lines, including visual references such as maps and images. A detail work flow with quality control measures and survey work will be provided.	Planning
Survey Control	Proposed surveying control to support airborne GNSS and any ground validation will be identified with details including base stations (active or passive) to be used, along with the reference information on the position control.	Planning

Ground Truthing	Details on planned ground validation and in-situ measurements, including location, and propose method for collecting ground survey data.	Planning
Data Processing	Details on the planned data processing including software, methods, filtering, any ancillary data to be used in data processing. A schematic work flow diagram showing the data processing steps and the quality control procedures incorporated in the processing will be included.	Planning
Quality Control	Data validation method, check for classification, accuracy verification, data voids, and other data checks. Information should include frequency and quantity sampled	Planning
Schedule	Planned schedule for airborne collection and ground truthing activities.	Planning

Considerations, Limitations and Assumptions

Any deviation from the project methodology will be provided to the contracting authority in advance of the data collection for review and approval.

6.1.2 Instrumentation

Description

A document is required that provides details on the airborne and ground survey equipment proposed for the project. The document should include specifications (including manufacturer, model and year) of the LiDAR sensor, the GNSS system used in the aircraft, the IMU sensor, and the ground survey instrumentation. The document should also include details regarding the calibration of the sensors including date of the last calibration. The document should be provided as part of the project deliverables.

Requirements

Table 3. Instrumentation requirements.

Name	Description	Category
Sensor Instrument	Details of the specific LiDAR sensor will be provided including manufacturer, year, model, ownership, most current calibration with date. A copy of the most current manufacturer's calibration for the complete system including laser, IMU, and GNSS system used maybe requested and upon request must be provided. Any sensor changes, failure or replacement prior or during the data collecting is required to be reported.	Planning

GNSS	The type of position sensors used in the acquisition (ground and airborne) is documented. Details to be provided include the manufacturer, year, and model. Any reference network information (active or passive) including number, location monuments, reference statement and published coordinates must be provided.	Planning
IMU	Provide details on the proposed IMU for the data collection including manufacturer, year, and model.	Planning

Considerations, Limitations and Assumptions

Any deviations from the proposed instrumentation must be communicated to the contracting authority for approval in advance of the data collection. The alternative instrumentation must be equal or better than planned sensors. The contracting authority may accept or reject proposed changes.

6.1.3 Data Collection Planning

Description

The minimum requirements for planning a collection of airborne LiDAR data are provided below.

Requirements

Table 4. Data collection planning requirements.

Name	**Description**	**Category**
Area of Interest (AOI)	A project area of interest is defined in the form of enclosed geographic boundaries using the coordinate system as identified in this guideline.	Planning
Data Collection Area of Interest (DCAOI)	A buffer of 100 metres is uniformly applied to the AOI and represents the actual data collection coverage. Data collected in the buffer area is to be submitted as part of the deliverables and must be collected to the same requirements as the data within the AOI.	Planning
Discrete Returns	The system used in the collection must be capable of collecting multiple discrete returns per pulse. At minimum, first and last returns are required. Intermediate returns are optional. Waveform data is optional.	Planning
Intensity	The intensity for each discrete return will be recorded and stored and as a 16-bit normalized value. A linear scaling will be applied as defined in ASPRS LAS 1.4 R13 on page 10.	Planning
Swath Overlap	A minimum of 15% swath overlap is required.	Planning

Considerations, Limitations and Assumptions

Airborne LiDAR data acquisition is dependent on using a reference control data source to precisely position the LiDAR pulses returns from the land surface. The reference control data for mapping the position of the pulse return use a range of global navigation satellite systems (GNSS). These systems include different constellations such as GPS, GLONASS, QZSS, Galileo or BeiDOU. However, the application of GNSS for positioning is affected by satellite geometry and solar flare which creates instability in the ionosphere. Therefore, it is recommended that a Position Dilution of Precision (PDOP) be less than 3, that a minimum of 7 satellites be in view, and that solar weather be checked prior and during data collection. A Single Ground base station for correcting GNSS signals should typically be within 25-35 km of field collection. Depending on the size and configuration of the DCAOI, two or more ground base control stations is recommended with baselines longer than 35km. Active control GNSS correction for RTK that use Continuous Operating Reference Stations (CORS) for real time correction or post processing such as Canadian Geodetic Survey PPP is permissible. The vendor must provide information on the positional method and ensure that the proposed solution meets the accuracy requirements of this guideline. Further information may be found in the *Guidelines for RTK/RTN GNSS Surveying in Canada* (2013).

- Cross-tie lines are flight lines acquired perpendicular to the planned data acquisition flight lines. Cross-tie lines provide data to support accuracy validation and can be used to support adjustment of data such as in periods of unexpected poor PDOP. It is strongly recommended that cross-tile lines be collected to support data quality assessment and validation.
- The requirement for swath overlap is a minimum of 15% to support quality assessment between adjacent swaths and to minimize potential data gaps. Actual overlapping swath used in the collection is at the discretion of the data collector to ensure the absence of data gaps in the useable portion of the swath (typically centre 95% of the swath width) and that the required data density is met.
- The scan angle used for airborne LiDAR data collection typically ranges from ±15 to ±30 degrees. Higher scan angles are discouraged as they result in increased footprint size thereby reducing pulse energy at the edges, increasing positional errors and scattering off the sides of vertical structures. In addition, when collection over undulating and/or high relief terrains, higher scan angles should also be discouraged. Best practice typical angles are between ±20 to ±25 degrees. The selection of a scan angle should consider vertical and horizontal accuracy requirements across the swath as well as per the project objective.

6.2 Data Collection

This section provides details when planning airborne LiDAR acquisition to meet minimum data collection requirements of CQL1 for topographic base mapping.

6.2.1 Conditions

Description

LiDAR data collection is affected by surface and atmospheric conditions which impact the quality and quantity of LiDAR pulse returns. This section describes the minimum requirements for airborne LiDAR acquisition with respect to the atmospheric, surface and other conditions.

Table 5. Data collection conditions requirements.

Name	Description	Category
Atmospheric	Collection should not take place during rain, snowfall, smoke or fog. No haze or clouds should be present between the aircraft and the ground.	Acquisition
Surface	Surface should be free from extensive flooding or inundation, snow cover and ice buildup on shoreline or land areas. Dry land surface condition is required. Frost is acceptable.	Acquisition
Tides	Areas affected by tides should be collected within 2 hours of the low tide. Low tide is time when the tide will be at its lowest point for given place and time the collection will take place.	Acquisition
Survey	Monitoring and recording of Global Navigation Satellite System conditions for Positional Dilution of Precision and solar activities during acquisition is required.	Acquisition
Temporal	Aside from the low tide requirement, there is no restriction on the time of day for LiDAR acquisition. Data may be acquired during day or night, provided data collection is compliant within any regulatory or legal conditions, and safety requirements are given paramount attention.	Acquisition

Considerations, Limitations and Assumptions

- The collection of LiDAR data is encouraged during river low flow (baseflow) conditions to maximize coverage of river banks and floodplains.
- At the discretion of the contract authority, the snow-free surface requirement may be waived for areas where there are permanent snowfields or glaciers.
- Except for specialized data collection projects focusing on vegetation (for example, forest biomass studies), leaf-off is a preferred vegetation condition, since it increases penetration to the ground and results in higher quality bare-earth surface (see Annex A). Leaf-on collection may be acceptable if the vendor collection method can demonstrate sufficient ground penetration to achieve accurate and reliable bare-earth surface that meet accuracy requirements. The contract authority will work with the vendor to determine acceptable vegetation conditions for LiDAR acquisition in the DCAOI.
- Very light non-drifting snow cover (less than 1cm) may be permissible at the discretion of the contracting authority.

6.2.2 Collection Pulse Density

Description

LiDAR pulse density and spacing for DCAOI is defined in this guideline as an aggregate nominal pulse density (ANPD) and aggregate nominal pulse spacing (ANPS). The aggregate pulse density/spacing is referred to as an overall pulse density/spacing whereby a swath may overlap other swaths completely, partially, or not at all. An overlapping swaths condition is achieved when a portion of the swath is covered with an adjacent flight line, flown on top of an existing swath with a single sensor, or acquired by two independent sensors using separate IMU's, with separate boresights on the same aircraft. A dual channel system using single Inertial Navigation System (INS) and boresight is considered to be acquiring single swath data. In swaths where a portion of the swath has no overlap then ANPD/ANPS is equivalent to Nominal Pulse Density and Nominal Pulse Spacing (NPD/NPS). See glossary for further definitions

Requirements

Table 6. Pulse density requirements and data voids.

Name	Description	Category
Pulse Density (ANPD)	≥ 2.0 pls/m^2 for first and only (single) pulse returns across DCAOI	Acquisition
Pulse Spacing (ANPS)	≤ 0.71 m	Acquisition
Laser Returns	Pulse data collection is based on laser pulse echo returns measured at the receiving sensor. At a minimum, first and last returns are required and intermediate returns are optional.	Acquisition

Considerations, Limitations and Assumptions

- ANPD and ANPS in this Guideline document refers to the net overall pulse density and pulse spacing from multiple independent sensors or multiple overlapping swaths. For single swath, ANPD and ANPS equal, respectively, to NPD and NPS.
- An intermediate pulse can provide addition information for applications involving forest/trees, transmission/distribution wires and buildings.

6.2.3 Data Collection Accuracy

Description

This section covers requirements for absolute and relative vertical and horizontal accuracy of LiDAR acquisition.

Requirements

Table 7. Data collection accuracy requirements.

Name	Description	Category
Vertical Accuracy – Non-vegetated (NVA)		
Vertical Root Mean Square Error ($RMSE_Z$)	≤ 10.0 cm	Acquisition
Vertical Accuracy – 95% confidence level (1.96 * $RMSE_Z$)	≤ 19.6 cm	Acquisition
Vertical Accuracy – Vegetated (VVA)	≤ 29.4 cm at 95th percentile	Acquisition
Fundamental Horizontal Accuracy (FHA)		
Horizontal Root Mean Square Error ($RMSE_r$)	≤ 35.1 cm	Acquisition
Horizontal Accuracy – 95% confidence level (1.7308 * $RMSE_r$)	≤ 60.0 cm	Acquisition
Calculated Horizontal Accuracy (CHA)	≤ 60.0 cm	Accuracy
Relative Vertical Accuracy		
Intraswath (smooth hard surface repeatability)	≤ 6 cm	Acquisition
Interswath (swath overlap difference – $RMSD_Z$)	≤ 8 cm	Acquisition

The Calculated Horizontal Accuracy (CHA) - Horizontal accuracy is influenced by GNSS positional errors, the angular errors arising from the IMU used and the flight altitude. A calculated horizontal accuracy will be derived using LiDAR Horizontal Error ($RMSE_r$) in *ASPRS 2014 Positional Accuracy Standards for Digital Geospatial Data* in Section 7.5 (see glossary for equation).

Considerations, Limitations and Assumptions

- The accuracy assessment should be conducted within the geometrically usable portion of the swath (typically the centre 95% of the swath width) and assumes that the horizontal and vertical accuracy of the ground control points are < 5 cm, 95% of the time (see Section 6.4.1 on checking accuracy)
- The relative vertical accuracy is used to examine geometric stability across all portions of the swath for data consistency. The overlap area can be considered as a measure of geometric alignment of two overlapping swaths with respect to positional shifts and vertical alignment. In addition, relative accuracy is a measure within the swath to detect any anomalous pulse data potentially due to laser issues and sensor related anomalies. The assessment is to be done at multiple locations throughout the DCAOI. See Data Validation section for more details.

6.3 Data Processing and Management

6.3.1 Data File Format

Description

Collected LiDAR point cloud data should be stored in the ASPRS LASer File Exchange format (LAS). For bulk storage of data, LAS files can be compressed into the lossless LAZ (LAS zip) format.

Requirements

Table 8. Data file format requirements.

Name	Description	Category
Standard	ASPRS LAS 1.4 – R13 will be used for storing LiDAR point cloud data. LAS 1.4 moves to 64-bit file structure.	Data Processing
Content	The Public Header information is to be completed.	Data Processing
Pulse Data Record	Record Formats 6, 7, 8, 9, or 10 are to be used for discrete pulse data. The format values depend if colour information is added and or wave packets are added to the LAS record structure.	Data Processing
Overlap and Overage	Overage pulses in the swath overlap region (i.e. points not part of the tenderloin) shall be identified as using overlap bit 3 flag as described in Table 16 in LAS 1.4 – R13 specification for Record Format 6. Applying a point classification field in any way for overage/overlap is not permissible. See definition of overage in glossary.	
Withheld Pulses	Withheld pulses due to noise, erroneous data points, and geometrically unreliable points should be retained using classification bit 2 as per Table 16 in LAS 1.4 – R13 specification.	Data Processing
Swath identification	A unique file identifier (File ID) for individual flight swaths must be applied prior to data processing and available to identify each swath to source as identified in LAS 1.4 specification. Each point within the swath must also be assigned a point source identifier (Point Source ID) that equals the unique file identifier. The unique file and point identifier must be persistent and preserved through the data processing steps.	Data Processing
Georeference	A correct and properly formatted geo-reference must be present in all LAS file headers. Open Geospatial Consortium (OGC)'s Well Know Text (WKT) is used for the required Coordinate Reference System (CRS).	Data Processing
Open Access	Only open LAS format is to be used and no proprietary formats are acceptable.	Data Processing

Compression	Compression of LAS form using an open source product is acceptable for data management. The compression must be lossless and converted seamlessly from and to LAS format, retaining all the information. LAZ format is the recommended compression format. The contracting authority will specify the file format required as the deliverable.	Data Processing
GPS Time	Each Global Navigation Satellite System (GNSS) aircraft positional measurement must be time stamped using Adjusted Global Positioning System (GPS) Time, at a precision sufficient to allow a unique timestamp for each LiDAR pulse. Adjusted GPS time is the satellite GPS time minus 1x10^9. The encoding tag in the LAS header shall be properly set.	Data Processing
Measurement Units	Measurements are in metres (m), and must be specified to a minimum of 3 decimal places.	Data Processing

Considerations, Limitations and Assumptions

- Georeferencing specifications is currently based OGC 2001 WKT standard which has since been deprecated. In 2015 OGC adopted the ISO WKT standards. However, ASPRS LAS standards is still based OGC 2001 WKT text. Change in georeferencing specification may be required in the future.
- Waveform data is considered optional and may be requested at the discretion of the contracting authority.
- All data collected within DCAOI shall be processed and provided as deliverables. No pulse data will be deleted from swath LAS files.

6.3.2 Pulse Classification

Description

All LiDAR pulse data, except pulses identified as Withheld, will undergo processing to be classified. All above ground level features (vegetation, buildings and other objects) shall be filtered to produce a “bare-earth” ground point data. The software, processing and use of ancillary data to achieve the classification accuracy threshold are at the discretion of the vendor. The classification schema will be based on LAS 1.4 – R13 specification for Point Data Record Format 6 – 10, Table 17. All pulses not identified as Withheld must be processed for classification. No data in LAS point cloud is to remain assigned to class 0 (created but not processed for classification).

Requirements

The minimum required class designation is identified below.

Table 9. Pulse classification requirements (LAS 1.4-R13 required classes).

Name	Description	Category
Classification	1 – Processed but unclassified 2 – Ground 9 – Water 7 – Low points (noise) 17 – Bridge decks 18 – High noise	Data Processing

Considerations, Limitations and Assumptions

- If breaklines are requested, it is recommended to include class 20 – Ignored ground (near a breakline). Note: ASPRS LAS Class 10 which has been used in the past for ignored ground points, is assigned to rail points.
- Point(s) created from techniques independent of LiDAR collection such as digitize from photogrammetric stereo model are considered Synthetic point(s). Synthetic points are discouraged and if used must be classified using bit field encoding set to 0. Details are to provided as part of the project reporting. See Table 16 ASPRS LAS 1.4 R13 specification for Synthetic point(s).

6.3.3 Coordinate Reference System

Description

The deliverable coordinate system of LiDAR data will be based on the current version of the Canadian Spatial Reference System (CSRS). Data will be represented in orthometric height and projected as listed below.

Requirements

Table 10. Coordinate Reference System requirements.

Name	Description	Category
Horizontal Datum	NAD83 CSRS, 2010 epoch	Data Processing
Vertical Datum	CGVD 2013	Data Processing
Geoid Model	CGG2013a	Data Processing
Map Projection	Universal Transverse Mercator (UTM)	Data Processing

Considerations, Limitations and Assumptions

- The processing of LiDAR pulse data should be conducted using a single UTM zone, except in locations where DCAOI extends into multiple zones and would result in unacceptable distortions to the data set. The data will then be split into subareas with appropriate UTM zones. Full tiles, with complete data coverage, should be maintained when data is split between UTM zones. One tile overlap into each zone should be maintained. Each subarea will be processed and provided as a separate subproject deliverable. The requirements applied to a project shall also apply to each subproject area.
- NAD83(CSRS) is a 3-dimensional geometric reference system whose realization is the current adopted national referencing standard in most federal and provincial agencies in Canada. It uses GRS80 as the reference ellipsoid and the current geoid model (presently CGG2013a) to convert from ellipsoidal heights to orthometric heights in the CGVD2013 vertical datum. NAD83(CSRS) coordinates can be expressed as geographical (latitude, longitude and ellipsoidal height) or UTM (easting, northing and height) coordinates and can be transformed to and from using geodetic transformation software from other reference system such as WGS84. GNSS receivers use WGS84 as the default coordinate reference system for ellipsoid heights. The Canadian Geodetic Survey (CGS) has a number of services and applications available to transform coordinates. The GPS-H software application provides the ability to transform GNSS derived data from ellipsoidal heights in either the ITRF coordinate reference systems (compatible with WGS84 which is currently aligned with ITRF08), or NAD83(CSRS) epoch's to orthometric heights in the CGVD28 or CGVD2013 vertical datum. The TRX software application provides the ability to transform coordinates between NAD83(CSRS) and various realization ITRF. It also includes the ability to convert between geographic, Cartesian and local coordinate systems. NAD83(CSRS) coordinates at the current epoch can also be directly obtained through post processing of raw static or kinematic GNSS data using Canada Active Control System (CACS) data and/or the online Precise Point Positioning (CSRS-PPP) service. The CSRS-PPP service uses the best available ephemerides and ionospheric corrections. The so-called "Ultra Rapid" products are used within approximately 90 minutes of data collection providing ±15 cm accuracy. The "Rapid" products are used within a day providing ±5 cm accuracy, and final products are used after 13 days to provide higher accuracy positions for raw observation data at ±2 cm. It is left data collectors to determine if CSRS-PPP solution would adequately meet CQL1 standards for location and time of data collection.
- EPSG codes are effective standards and efficient means of assigning coordinate reference system. There are currently 52 different EPSG codes for the different projected coordinate system and one for the NAD83CSRS (EPGS::6140). However, EPSG code 6140 treat the different realization and epochs of NAD83CSRS as the same and does not recognize the subtle differences. In Canada each province have adopted different realization and epoch of NAD83CSRS. These are currently not recognized at the time of this publication but is expected to be updated in EPSG registry. In future, the use of EPSG codes as coordinate reference system is worth considering for adoption.
- Virtual Reference Systems (VRS) are based on a network of GNSS receivers that are spaced apart at a separation distance on the order of about 40-60km. The GNSS receivers act as Continuously Operating Reference Stations (CORS). The information collected by GNSS receivers actively broadcast the localized correction to the network. The corrections are uploaded for real-time monitoring and correction of static and RTK GNSS receivers.

When using VRS control, it is recommended to implement appropriate calibrations and checks for verification and validation of the data and results. VRS receivers provide another potential source for control of GNSS airborne and ground receivers. The use of these networks is permissible at the discretion of the vendor and contracting authority to ensure accuracy requirements are met.

6.3.4 Point Families

Description

A transmitted LiDAR pulse can have one to many returns. The complete set of multiple returns reflected from a single LiDAR pulse is considered a point family.

Requirements

Point families (multiple return “children” of a single “parent” pulse) will be maintained throughout all processing before tiling. Multiple returns from a given pulse will be stored in sequential (collected) order.

Considerations, Limitations and Assumptions

Systems with multiple channel lasers or multiple points in air will maintain pulse families for each single pulse.

6.3.5 Tiling Scheme

Description

The processing of LIDAR data will include preparing and delivering the data using a tiling scheme.

Requirements

Table 11. Tiling scheme requirements.

Name	Description	Category
Size	1 km x 1km	Data Processing
Condition	Edge-match seamlessly, no gaps or overlap	Data Processing
Naming	Each tile will be named following a name standard identified below.	Data Processing
Georeferencing	Coordinate Reference System and units of the data will be used.	Data Processing
Type	Pulse, point and raster data will use the same tiling scheme.	Data Processing
Format	Data tiles will be produced in LAS or LAZ format as determined by the contracting authority.	Data Processing
Index file	A digital index file as ESRI shapefile must be provided with the data, with file naming convention in the attribute table, including separate fields for index reference, project name, collection date.	Data Processing

Tiles will be created with a unique naming convention using the following principles:

- The structure should be designed in a manner that is readily programmable.
- Each tile must be uniquely defined in the data sets both in time and position, so there is no duplication.
- File names should be easy to interpret and clearly identify the file's content.
- Naming should be consistent with standards such as using address codes for provinces and territories.

In Table 12, a recommended file naming convention for LiDAR data is summarized.

Table 12. File naming conventions for LiDAR data.

Name	Description	Example
Province/Territory	Abbreviate names using postal addressing standards.	ON, BC, YK etc.
Project Name or ID	Short project name (max 20 characters) typically a geographic reference such as city, town, watershed, region	Kitmat, BanffPark, LongPoint, 2698A
Project Collection Date	Year and month date field (YYYYMMDD) of Acquisition end date	20170511
Coordinate Reference System	A reference to coordinate reference system or map projection	NAD83CSRS_UTMZ9
Tile Size	The square kilometre tile size	1km

Tile Corner Coordinate	Using the southwest corner of the tile, assign the UTM easting and northing. Use 4 digits for easting and 5 for northing - EXXXX_NYYYYY	E5237_N59906
Quality Level	Use the value for the quality level of the data product field.	CQL1
Product	A short field name for LiDAR products produced such as classified point data, data merged with orthophotos or derivative products such as DSM.	CLASS – Point Cloud Classification CLASSRGB DTMR – Bare Earth DTM Raster BEP – Bare Earth – Ground Point Data DSMR – Digital Surface Model Raster UNCLASS – Unclassified Point Cloud INT – Intensity Image HS – Hillshade CHM – Canopy Height Model Etc.
File Extension	Standard file extensions used	LAS, LAZ, TIF, shp

Format would consist of the following:

P/T_ProjectNameorID_ProjectCollectionDate(YYYYMMDD)_CoordinateReferenceSystem_TileSize_TileCorner(SW)EXXXX_NYYYYY_QualityLevel_Product.extension

Example:
BC_Kitmat_20170511_NAD83CSRS_UTMZ9_1km_E5237_N59906_CQL1_CLASS.LAS

Considerations, Limitations and Assumptions

The data collected along the edge of AOI will be generated using the DCAOI (buffered AOI) and then clipped to the AOI to avoid any edge effects.

6.3.6 Derivative Products

Derivative products, with the exception of pulse classifications, have been considered outside the scope of this guideline. However, some products such as gridded and raster DTM, intensity and hillshade images may be generated to support the quality assessment. For more information on derivative products see *High Resolution Digital Elevation Model (HRDEM) – CanElevation Series -Product Specification Edition 1*.

6.4 Data Validation

6.4.1 Quality Checks

The quality assurance of LiDAR data with respect to this guideline involves implementing and conducting data validation procedures to provide confidence that the quality requirements are fulfilled. In this guideline, several quality control procedures have been specified as independent quality checks to assess if the LiDAR data requirements are being satisfied. The quality check includes the following:

Positional Accuracy
Spatial Distribution and Regularity
Pulse Density
Pulse Classification
Data Voids
Relative Accuracy

The contracting authority is responsible for selecting a party to conduct all or part of the independent quality checks. The party may be a single or multiple independent organizations, an in-house resource or data collection vendor.

6.4.2 Positional Accuracy

Description

The verification of LiDAR positional accuracy both horizontal and vertical should be conducted using independent check points. Check points should be divided into non-vegetated and vegetated areas. Check points may be acquired by a vendor collecting the LiDAR data, by the contracting authority, or by an independent third party at the discretion of the contracting authority. The check point collection process involves selecting a sampling areas size, sampling area land cover types, number of sampling areas and number of check points to be collected. The check point validation process should follow, at a minimum, the ASPRS guidelines for Positional Accuracy Standards for Digital Geospatial Data 2014 (ASPRS 2014). The ASPRS guidelines provide the recommended number of check points for horizontal and vertical accuracy assessment of elevation data as a function of AOI area (Table C.1). The check points will be conducted for Non-Vegetated Vertical Accuracy (NVA), Vegetated Vertical Accuracy (VVA), and Fundamental Horizontal Accuracy (FHA) assessments as described below.

Requirements

Table 13. Check point requirements.

Name	Description	Category
Non-Vegetated Vertical Accuracy (NVA)	The check points for NVA assessment areas will be surveyed in clear open areas devoid of vertical features (such as vegetation, vehicles, pipes, wires, etc.) where LiDAR pulses	Validation

	have single returns. Survey area must have a minimum size of (ANPS x 5)^2 and should use flat ground with slope less than 10 degrees. Acceptable land cover type includes open areas of low grass, such as lawns and golf courses, bare earth and urban paved areas. Distribute the sampling areas where the surface has been altered such as plowed fields are not acceptable. The survey should be adequately distributed to cover the whole AOI and all varieties of land cover types within it. NVA accuracy requirements the following: Vertical Root Mean Square Error ($RMSE_Z$) ≤ 10.0 cm Vertical Accuracy – 95% confidence level (1.96 * $RMSE_Z$) ≤ 19.6 cm	
Vegetated Vertical Accuracy (VVA)	The assessment of VVA will be conducted in vegetated areas, such as tall grass, crops, brush land, short trees and forests. The survey area must have a minimum size of (ANPS x 5)^2 and flat ground (slope less than 10 degrees). Vertical Accuracy – Vegetated (VVA) ≤ 29.4 cm at 95th percentile	Validation
Fundamental Horizontal Accuracy (FHA)	The check points for assessment of Fundamental Horizontal Accuracy should be acquired over well-defined linear features with distinct breaks in elevation or intensity, such as road markings, buildings, walls, railway tracks and road pavement edges. Areas must be flat (slope less than 10 degrees) with hard or compacted surfaces. Horizontal Root Mean Square Error ($RMSE_r$) ≤ 35.1 cm Horizontal Accuracy – 95% confidence level (1.7308 * $RMSE_r$) ≤ 60.0 cm	Validation

The absolute vertical and horizontal accuracy will be evaluated against NVA and VVA check points. The vertical accuracy check is also conducted for the final DTM for NVA and VVA. The DTM check requirements will be provided by the contracting authority.

- The accuracy assessment assumes the errors are normally distributed and therefore metrics such as RMSE are statistically valid. An alternative numerical method would be required if the errors were not normally distributed.
- The number of checkpoint sampling areas for conducting combined accuracy assessment is based ASPRS The designated checkpoint sampling area is a homogeneous flat area equivalent to (ANPS x 5)^2. For projects with an AOI less than 500 km^2 a minimum number of check points sampling areas is determine by the contracting authority. For projects that are greater than 500 km^2 and less than 2,500 km^2 the number of check points will be a linear expansion of the ASPRS 2014 Table C.1 as a minimum sampling area amount which is approximately ~ 1 checkpoint per 25 km^2. The contracting authority may request additional

check points be conducted by the vendor or independently to verify the accuracy of the data. This may include selecting areas of diverse ground cover and topography. For vertical assessment of areas >2,500 km^2, add five additional vertical checkpoints for each additional 500 km^2 area. Each additional set of five vertical checkpoints for 500 km^2 would include three checkpoints for NVA and two for VVA. The recommended number and distribution of NVA and VVA checkpoints may vary depending on the importance of different land cover categories and Contracting Authority requirements. For horizontal testing of areas >2500 km^2, Contracting Authority should determine the number of additional horizontal checkpoints, if any, based on criteria such as resolution of imagery and extent of urbanization.

- The fundamental Horizontal Accuracy (FHA) assessment will involve sampling over surfaces with clear linear features or easily identifiable features on ground, seen using interpolated intensity images.
- In general, the minimum number of check points to be collected shall be no less than 20 points, and preferably 30 points evenly distributed across the project AOI and proportional distributed for NVA and VVA as recommend in ASPRS Positional Accuracy Standards for Digital Geospatial Data version 1 November 2014. Checkpoints may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. The contracting authority may adjust the number of check points collected in locations of concern or due to challenging areas for NVA, VVA and FHA
- Check points will not be surveyed in areas of extremely high NIR absorption (fresh asphalt, wet soil, or building roofs with asphalt surface), or in areas that are near abrupt changes in NIR reflectivity (white beach sand adjacent to water) because such abrupt changes usually cause unnatural vertical shifts in LiDAR elevation measurements.
- In land covers other than forested and high-density urban, the check points should have no obstructions above 15 degrees over the horizon (to improve GNSS reception and maximize LiDAR pulse collection).
- Check points shall be an independent set of points used for the sole purpose of assessing the vertical and/or horizontal accuracy of the data collection and cannot have been used in calibration or integrated into the data acquisition.
- Survey of check points with each assessment type (NVA, VVA and FHA where possible) will be well-distributed across the entire AOI.
- The accuracy requirement for survey check points is ≤ 5 cm at 95% confidence. The contracting authority may specify a higher degree of accuracy with survey check points. Vertical check points should be three times more accurate than the required accuracy of the elevation data set being tested. In addition to newly acquired survey check points, historical points may be used, provided they were acquired within the last 3 years and not used in calibration or data acquisition of the current project. Historical points must meet all the check points requirements and surface conditions at the check point location must be temporally invariant and verifiably undisturbed. The contracting authority must be advised in advance if historical points will be used and reserves the right to reject any or all points.
- Vertical accuracy testing of point data will use a TIN model to conduct the comparison between point data and check points. First and only pulse data will be used to create a TIN. The TIN will be used to extract an interpolated value at the location of the ground sample check points were collected for the comparison.

Considerations, Limitations and Assumptions

- All required check points are to be collected within the AOI. However, at the discretion of the Contracting Authority supplementary checkpoints may be collected with 100m buffer areas.
- In some DCAOI, access restrictions, safety, difficult terrain, and transportation constraints may prevent the desired spatial distribution of checkpoints across land cover types; Where it is not geometrically or practically applicable to meet the recommended checkpoint collection targets, data vendors in conjugation with the Contracting Authority, should use their best professional judgment to apply the spirit of that method outlined in ASPRS Positional Accuracy Standards for Digital Geospatial Data version 1 November 2014 in selecting locations for checkpoints.

6.4.3 Spatial Distribution and Regularity

Description

The spatial distribution of pulses within the geometrically usable portion of the swath (typically 95% of the centre portion of the swath width) will be collected with a uniform distribution to represent a regular lattice distribution. Although LiDAR sensors do not collect in regular distributed pattern, the collection shall be designed and carried out to produce an aggregate first and only return point cloud that approach a regular lattice of pulses as defined in the requirements below.

Requirements

Table 14. Classification accuracy requirements.

Name	Description	Category
Spatial Distribution and Regularity	Uniformity of the spatial distribution and regularity of pulses distribution is assessed through a distribution grid using individual (single) swaths with the first and only return pulses within the geometrically usable centre part of each swath and excluding acceptable data voids. The resolution of the distribution grid should be twice the design ANPS. The grid cells will be round up to nearest integer grid cell size. The uniformity requirement is to have at least 1 pulse per distribution grid cell at least 90% of the time.	Validation

Considerations, Limitations and Assumptions

- The approach used to count LiDAR pulses within the distribution grid will be dependent on the software tool used. Some software tools use a count based on pulses that fall within the grid cell and others use a search radius to count pulses that fall within a grid. For software tools that use a search radius approach for determining counts within a grid cell, the search radius shall be equal to the design ANPS.
- The assessment excludes acceptable data voids as identified in Section 6.4.4
- This analysis is only related to regular and uniform point distribution. The assessment is not for assessing ANPD or NPD across the DCAOI (see Section 6.4.3)
- The concession of this threshold in difficult areas such as high relief may be waived at the discretion of the contracting authority

6.4.4 Pulse Density Check

Description

A data check is conducted to verify that ANPD has been achieved across the DCAOI. A pulse density grid is used to assess whether the pulse density has achieved for the specified CQL. The specific requirement is identified in the table below:

Requirements

Table 15. Pulse density check requirements.

Name	Description	Category
Pulse Density Grid	Pulse density verification will be conducted using a 20m x 20m pulse density grid covering all DCAOI.	Validation
Evaluation	ANPD must be satisfied at least 90% of time within the pulse density grid cells for DCAOI based on first and only returns. A visual grid output with red cells showing below ANDP and green for cells meeting ANDP requirement. A histogram distribution will be used to quantify the pulse density distribution.	Validation

Considerations, Limitations and Assumptions

Insufficient pulse density may result in the requirement to reacquire data in deficient areas at the discretion of the contracting authority.

6.4.5 Data Voids

Description

Gaps in LiDAR point cloud data can occur as a result of surface absorption or refraction in the near-infrared, sensor issues, processing anomalies, and improper data collection. Data voids arising from errors in collection and processing must be identified and corrected. Data voids are not permitted in the DCAOI as outlined in the requirements.

Requirements

Table 16. Classification accuracy requirements.

Name	Description	Category
Data voids	A data void is any area greater than or equal to 4 x $(\text{ANPS})^2$ which is measured using first and only returns. Data voids within a single swath are not acceptable, except where caused by water bodies or low near infrared reflectivity areas, or where voids have been appropriately filled in by data from another swath. Overlapping swath used for fill in must meet all requirements as specified in this guideline	Validation

Considerations, Limitations and Assumptions

Data voids larger than the threshold may result in vendor requiring to re-fly at the discretion of the contracting authority

6.4.6 Pulse Classification Accuracy

Description

The classification of pulse data is an iterative process involving software tools and ancillary information to convert the pulse data into land cover type classes. The process can involve automated and semi-automated software routines with ancillary data to produce point cloud classified data. An accuracy assessment is applied to evaluate if the required quality is achieved. The specific classification accuracy assessment is identified below.

Requirements

Table 17. Classification accuracy requirements.

Name	Description	Category

Test Area	Using a 20m x 20m grid	Validation
Accuracy	No more than 2% of non-withheld points can have a demonstrable classification error within AOI.	Validation
Assessment	The assessment of the classification should be tested by comparing known ground control points and/or using ancillary information including high resolution ortho imagery or other relevant geospatial data sets. Sampling should be well distributed across the AOI. A minimum of 5 grid cells per sq. km will be sampled. The contracting authority may increase the sampling requirements.	Validation
Consistency	Point classification must be consistent across the entire project. Variations in the character, texture, or quality of the classification between tiles, swaths, flights, or other unnatural divisions are grounds for rejection of the entire deliverable.	Validation

Considerations, Limitations and Assumptions

Classification may be relaxed by the contracting authority for challenging areas.

6.4.7 Relative Accuracy Check

Description

The accuracy of pulse returns should be consistent across the useable portion of a single swath and in the overlap areas of swaths. The relative vertical accuracy checks are used to validate the geometric stability of the data collection.

Requirements

Table 18. Relative accuracy requirements.

Name	Description	Category
Relative Vertical Accuracy – Intraswath (smooth hard surface repeatability)	Intraswath assessment will use a single swath with only single returns in a non-vegetated area. The assessment will be conducted on smooth hard surfaces to determine vertical elevation discrepancy not to exceed the threshold of ≤ 6 cm calculated using Root Mean Square Difference ($RMSD_Z$) between the minimum and maximum. The assessment will use a gridded signed difference raster with cell size equal to 2 x ANPS rounded up to closes	Acquisition

	integer. The sampling area will be approximately 50 m^2 and will be conducted for multiple locations both across the swath and along the swath within the usable portion of the swath. A minimum of three sample area per swath for all swaths in AOI. The contracting authority may request or conduct additional sampling. The sampling area will be evaluated with a signed difference raster between the maximum and minimum elevation for each grid cell. The raster difference must not exceed the table value for intraswath relative accuracy.	
Relative Vertical Accuracy – Interswath (swath overlap difference - RMSDz)	The assessment of two swaths for interswath consistency is achieved by generating a gridded raster from single returns in non-vegetated area. The comparison will use gridded signed difference raster with a cell size equal to 2 x ANPS rounded up to the closest integer for each swath. The assessment is conducted by subtracting the difference between the grid surfaces. Root Mean Square Difference ($RMSD_Z$) between minimum and maximum calculated for the points in the raster surface should not exceed ≤ 8 cm.	Acquisition

Considerations, Limitations and Assumptions

Hillshade raster images are useful for identifying anomalies in the data processing stream.

6.5 Project Deliverables

A comprehensive Project Report must be provided that includes assembly of all content including documentation, images, notes and data created from the project.

6.5.1 Deliverable Items

Project Reporting

Table 19.Report deliverables

Item	Description	Format
Project Planning	Content includes the following: • Project method details (Section 6.1.1) • Instrumentation details (Section 6.1.2) • Data collection (Section 6.1.3)	Microsoft Word or PDF

Progress Reports	During the acquisition, progress reports shall be provided at frequency stipulated by the contract authority. • On/off schedule • Status of collection % completion and where • Any changes to the collection plan including people or instrumentation • Any current issues causing delay • Any anticipate issues that affect data collection, budget, or the schedule	Microsoft Word or PDF
Project Deliverables	Project deliverable reporting items will include the following: • Field notes for surveying, flight logs • The Data Quality Assurance report with detail of data validation for vertical and horizontal accuracy, check points collection, classification accuracy check, regularity and pulse density check, all calculation and results • The Deliverable Report contains an assembly of information related to all deliverables provided and processing, data list, and metadata. It should contain sufficient detail to demonstrate the specifications have been met for each pulse data collected.	Microsoft Word or PDF
Data Inventory List	A data inventory and dictionary descripting all the data and documentation collected in the project will be provided in a structured table list. It will include file name, creation date, description and a contact responsible for the items.	Microsoft Excel or PDF

Field Data

Table 20. Field data deliverables

Item	**Description**	**Recommended Format**
Survey Control	• Active or passive station data including location and any monument station, date time stamp, GNSS data collected should be included • Control points used to calibrate and process the pulse data • Photos of survey control and a map of the base station locations	RINEX, PDF
Flight	• Flight trajectory – SBET files – including any tie lines or calibration flights. A shapefile with all the trajectory, orientation, time, date information should be retained.	Shapefile

	Flights should be separated by lifts and by logical separation such as flight blocks.	
In-situ Validation	• Check point measurements • All GNSS field and control data including parameters for collection • Photographs of site of measurement areas - both ground and site views • Map of the locations of the check point areas and the classification checks	Excel RINEX/MS Word-PDF TIFF/JPG PDF/JPG
Metadata	Metadata will be provided for the field data. The structure of the metadata will use XML format using ISO 19115:2003 standard.	XML

LiDAR Data

Table 21. LiDAR data deliverables.

Item	Description	Format
Point Cloud Data	Classified point cloud data in tiles using naming conventions	LAS/LAZ
Index File	Index file of point cloud data with date, naming convention, project name, location	shapefile
Raw data	Not required for delivery, except if desired by the contracting authority or when final point cloud data is not delivered. Vendor must retain a master copy of the raw data for a period of 6 month from the date of delivery.	
Metadata	Metadata on the data delivery in XML format using ISO 19115:2003 standard North American Profile and supplemental information on the LiDAR acquisition	XML (Metadata) Excel (Supplemental information on the LiDAR acquisition)

Supplemental information on the LiDAR acquisition

The *Supplemental information on the LiDAR acquisition* shall be included in an Excel file to complement the Metadata ISO 19115:2003 standard North American Profile.

• classification_code	LAS Class used
• ldr_sensor	LiDAR Sensor Used
• ldr_max_number_return	Maximum number of returns per pulse
• ldr_aggregate_density	ANPD
• ldr_flight_height	Flight Height (m)
• ldr_flight_speed	Flight speed (knts and km/hr)
• ldr_scan_angle	Scan Angle (degrees)
• ldr_scan_frequency	Scan Frequency (Hz)
• ldr_pulse_rate	Pulse Repetition Frequency (kHz)
• ldr_pulse_width	LiDAR pulse footprint size (m)
• ldr_wave_length	Sensor wavelength (nm)

ldr_multi_pulse_in_air	Whether the sensor was operated with Multiple Pulses In The Air, 0=No; 1=Yes.
ldr_beam_divergence	Beam Divergence (mrad)
ldr_swath_width	Swath with (m)
ldr_swath_overlap	Swath overlap (%)
las_version	LAS version used (e.g. v1.4)
las_overlap	Points classified in areas overlap
las_withheld	Detail description on points removed as noise, low points, or anomalous points.
las_intensity_resolution	Intensity bit resolution

Data Validation

Table 22. Data Validation Deliverables

Item	Description	Recommended Format
Spatial Distribution and Regularity	Results from checking the distribution pulse data	Excel and PDF
Relative Accuracy	Calculation of relative accuracy including all data used for: • Intraswath comparison • Interswath comparison	Excel, GeoTiff, PDF
Pulse Density	Visual grid and histogram - calculated result from applying the pulse density grid	GeoTiff
Data Voids	Results from conducting a data void check.	Excel, GeoTiff, and PDF
Pulse Classification	Summary of classification results	Excel, GeoTiff and PDF
Positional Accuracy	The results of positional accuracy including all data used for check point location for vertical and horizontal – NVA, VVA, FHA and CHA will be provided.	Excel, GeoTiff and PDF

6.5.2 Raw LiDAR Data

Raw project source data, such as native format LiDAR files, are NOT required for delivery. However, the Vendor must hold a copy of all relevant raw project data, for a minimum time as specified in Table 21 or an agreed upon time between the contracting authority and vendor beyond the final delivery of the project deliverables. This period is considered a review period to ensure all deliverables are met. During this period, additional quality control and assurance testing may be conducted as needed and determined by the contracting authority. If any deficiencies are found in the deliverables, content, and data (i.e: not meeting the specifications guideline), the contractor authority may reject the data, requiring completion of the deliverables or reprocessing or re-flying of deficient areas at a timeline specified by contracting authority.

6.6 Data Ownership and Copyright

It is recommended that the vendor must deliver all the data with unrestricted copyright, and the ability for the contract authority to place the data within the public domain or distribute as the contracting authority sees fit. The specific arrangement is to be determined by the contracting authority and the vendor. This recommendation is strongly encouraged for any data acquired through federal funds.

7.0 GLOSSARY

95% Confidence Level: Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. Where errors follow a normal error distribution, vertical accuracy is defined at the 95% confidence level, and horizontal accuracy at the 95% confidence level (NDEP 2004).

95th Percentile: Accuracy reported at the 95th percentile indicates that 95% of the vertical errors will be of equal or lesser value of the specified accuracy and 5% of the vertical errors will be of larger value. This term is used when vertical errors may not follow a normal error distribution, e.g., in forested areas where the classification of ground elevations may have a positive bias.

Accuracy: The degree of conformity of a measured or calculated value compared to the actual value. Accuracy relates to the quality of a result and is distinguished from precision, which relates to the quality of the operation by which the result is obtained (ASPRS Guidelines for Procurement).

- **Absolute Accuracy:** A measure that accounts for all systematic and random errors in a dataset. Absolute accuracy is stated with respect to a defined datum or reference system.
- **Relative Accuracy:** A measure of variation in point-to-point accuracy in a data set. In LiDAR, this term may also specifically mean the positional agreement between points within a swath, adjacent swaths within a lift, adjacent lifts within a project, or between adjacent projects.

Aggregate Nominal Pulse Density (ANPD): A variant of nominal pulse density that expresses the total expected or actual density of pulses occurring in a specified unit area resulting from multiple passes of the light detection and ranging (LiDAR) instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. In all other respects, ANPD is identical to nominal pulse density (NPD). In single coverage collection, ANPD and NPD will be equal. Note:

NPD = $1/\mathrm{NPS}^2$

Aggregate Nominal Pulse Spacing (ANPS): A variant of nominal pulse spacing that expresses the typical or average lateral distance between pulses in a LiDAR dataset resulting from multiple passes of the LiDAR instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. In all other respects, ANPS is identical to nominal pulse spacing (NPS). In single coverage collections, ANPS and NPS will be equal. Note:

NPS = $\frac{1}{\sqrt{NPD}}$

Attitude: The position of a body defined by the angles between the axes of the coordinate system of the body and the axes of an external coordinate system. In photogrammetry, the attitude is the angular orientation of a camera (roll, pitch, yaw), or of the photograph taken with that camera, with respect to some external reference system. With LiDAR, the attitude is normally defined as the roll, pitch and heading of the instrument at the instant an active pulse is emitted from the sensor.

Bare Earth (Bare-earth): This refers to the digital elevation data of the terrain, free from vegetation, buildings and other man-made structures (elevations of the ground)

Boresight: Calibration of a LiDAR sensor system equipped with an Inertial Measurement Unit (IMU) and Global Positioning System (GPS) to determine or establish the accurate:

- Position of the instrument (x, y, z) with respect to the GPS antenna
- Orientation (roll, pitch, heading) of the LiDAR instrument with respect to straight and level flight.

Breakline: This is a linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line.

Calculated Horizontal Accuracy (CHA): CHA is the horizontal accuracy determined by the following formula from ASPRS 2014 Positional Accuracy for Digital Geospatial Data:

$$LiDAR\ Horizontal\ Error\ (RMSEr) = \sqrt{(GNSS\ positional\ error)^\wedge 2\ \ + (\tan(IMU\ error)/0.5594170\ \ x\ flying\ altitude)^\wedge 2}$$

Calibration: This refers to the process of identifying and correcting for systematic errors in hardware, software, or procedures. Calibration can also be defined as determining the systematic errors in a measuring device by comparing it’s measurements with the markings or measurements of a device that is considered correct. Airborne sensors can be calibrated geometrically and radiometrically.

Check Point: A check point is a surveyed point used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy. Check points are independent from, and may never be used as control points on the same project.

Classification: This refers to the classification of LiDAR point cloud returns in accordance with a classification scheme to identify the type of target from which each LiDAR return is reflected. The process allows future differentiation between bare-earth terrain points, water, noise, vegetation, buildings, other man-made features and objects of interest.

Control Point: A control point is a surveyed point used to geometrically adjust a LiDAR dataset to establish its positional accuracy relative to the real world. Control points are independent from, and may never be used as check points on the same project.

Data Void: In LiDAR, a data void is a gap in the point cloud coverage, caused by surface non-reflectance of the LiDAR pulse, instrument or processing anomalies or failure, obstruction of the LiDAR pulse, or improper collection flight planning. Any area greater than or equal to four times the aggregate nominal pulse spacing (ANPS) squared, measured using first returns only, is considered to be a data void.

Datum: A datum consists of a set of reference points on the Earth's surface against which position measurements are made, and (often) an associated model of the shape of the earth (reference ellipsoid) to define a geographic coordinate system. Horizontal datum (for example, the North American Datum of 1983 Canadian Spatial Reference System (NAD83 (CSRS)) are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system. A vertical datum, for example the Canadian Geodic Vertical Datum 2013, measures elevations or depths. In engineering and drafting, a datum is a reference point, surface, or axis on an object against which measurements are made.

Digital Elevation Model (DEM): A DEM is a digital representation of relief composed of an array of elevation values referenced to a common vertical datum and corresponding to a regular grid of points on the earth's surface. These elevations can be either ground or reflective surface elevations.

Digital Terrain Model (DTM): A DTM is a representation of the bare ground surface without any objects such as vegetation and buildings.

Digital Surface Model (DSM): A DSM is a representation of the earth's surface including vegetation and man-made structures. The Digital Surface Model (DSM) provides the height of the vegetation, canopies and structures above the vertical datum.

Discrete Return: This is a LiDAR system or data in which important peaks in the waveform are captured and stored. Each peak represents a return from a different target, discernible in vertical or horizontal domains. Most modern LiDAR systems are capable of capturing multiple discrete returns from each emitted laser pulse.

Field of View (FOV): This is the angular extent of the portion of object space surveyed by a LiDAR sensor, measured in degrees. To avoid confusion, a typical airborne LiDAR sensor with a field of view of 30 degrees is commonly depicted as ±15 degrees scan angle on either side of nadir.

First Return: This is the first important measurable part of a returned LiDAR pulse.

Grid: A grid is a geographic data model that represents information as an array of equally sized square cells. Each grid cell is referenced by its geographic or x/y orthogonal coordinates.

Horizontal Accuracy: Horizontal accuracy compares horizontal positions of precisely known and easily discernible ground/check points to LiDAR ground point positions reported as RMSE or error at 95% confidence level (ASPRS 2014). Horizontal accuracy is defined as a radius of a circle of uncertainty and assumes a normal distribution. At 95% confidence, radial horizontal accuracy is defined as:

Horizontal Accuracy = 1.7308 x RMSE_r

Where

$$RMSE_r = \sqrt{RMSE_x{}^2 + RMSE_y{}^2}$$

$$RMSE_x \ or \ RMSE_y \ = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{i(LiDAR)-}\ x_{i(Survey)}\ )2}$$

Note that $x_{i(LiDAR)}$ are set of LiDAR points being evaluated and $x_{i(Survey)}$ are the corresponding survey check points used to compare the LiDAR horizontal (r) points at that geographic location. *n* is the number of check points.

Intensity: For discrete return LiDAR instruments, intensity is the recorded amplitude of the reflected LiDAR pulse at the moment the reflection is captured as a return by the LiDAR instrument. LiDAR intensity values can be affected by many factors, such as the instantaneous setting of the instrument's automatic gain control and angle of incidence and cannot be equated to a true measure of energy. In full-waveform systems, the entire reflection is sampled and recorded, and true energy measurements can be made for each return or overall reflection. Intensity values for discrete returns derived from a full-waveform system may or may not be calibrated to represent true energy.

Inertial Navigation System (INS): INS is a navigation aid that uses a computer control system, Inertial Measurement Unit (motion sensors (accelerometers) and rotation sensors (gyroscopes)) coupled with a Global Navigation Sensor System such as Global Position System to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of the aircraft.

LAS: This is a public file format for the interchange of 3D point cloud data between data users. The file extension is .las.

Lattice: A lattice is a 3D vector representation method created by a rectangular array of points spaced at a constant sampling interval in x and y directions relative to a common origin. A lattice differs from a grid in that it represents the value of the surface only at the lattice mesh points rather than the elevation of the cell area surrounding the centroid of a grid cell.

Last Return: This is the last important measurable part of a return LiDAR pulse.

LiDAR: LiDAR stands for Light Detection and Ranging and is an instrument that measures 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.

Lift: A lift is a single takeoff and landing cycle for a collection platform (fixed or rotary wing) within an aerial data collection project, often LiDAR.

Metadata: Metadata is any information that is descriptive or supportive of a geospatial dataset, including formally structured and formatted metadata files, reports, and other supporting data.

Multi-channel LiDAR: Multiple channels of data from a single instrument are regarded as a single swath. In this sense, a single instrument is regarded as one in which each channels meet the following criteria:

- They share fundamental hardware components of the system, such as global positioning system (GPS), Inertial Measurement Unit (IMU), laser, mirror or prism, and detector assembly,
- They share a common calibration or boresighting procedure and solution, and
- They are designed and intended to operate as a single-sensor unit.

Nadir: This is the point or line directly beneath the collection platform, corrected for attitude variations. In LiDAR, this would correspond to the centerline of a collected swath.

Overlap: This is the percent of overlap associated with two adjacent flight lines that happens as a result of the plane flying back and forth through the project area to achieve desired uniform data density and optimal ground cover under canopy

Overage: Overage corresponds to those parts of a swath that are not necessary to form a complete single, non-overlapped, gap-free coverage with respect to the adjacent swaths. They are the non-tenderloin parts of a swath. In collections designed using multiple coverage, overage are the parts of the swath that are not necessary to form a complete non-overlapped coverage at the planned depth of coverage. In the LAS Specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2011), these points are identified by using the incorrectly named “overlap” bit flag. See overlap, tenderloin.

Point Cloud: Often referred to as the “raw point cloud”, this is the primary data product of a LiDAR instrument. In its crudest form, a LiDAR raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation associated with each laser pulse is converted to a position in a three-dimensional frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each emitted laser pulse. In addition to spatial information, LiDAR intensity returns provide texture or color information.

Point: A point is defined in the guideline as LiDAR pulse that has been collected, validated and classified.

Pulse: A laser pulse is the transmission of electromagnetic energy from a coherent light source using a laser at a specific wavelength.

Pulse footprint: This is the area of ground intersected by the laser pulse. It is a function of range, angle of incidence, slope of the ground and beam divergence. Pulse footprint energy distribution is define by a Gaussian distribution as 1/e or 1/e^2 depending on sensor used.

Pulse Repetition Frequency (PRF): PRF is the frequency of transmitted laser pulses. High PRF enables dense point-spacing on the ground providing higher-resolution descriptions of the landscape. However, since PRF is inversely related to pulse energy, high PRF might reduce the probability of foliage penetration in densely vegetated areas.

Raster: is a matrix of rows and columns of pixels that contain a value and can represent a surface. See Grid

Spatial distribution: In LiDAR, spatial distribution is the regularity or consistency of the point density within the collection. The theoretical ideal spatial distribution for a LiDAR collection is a perfect regular lattice of points with equal spacing on X and Y axes.

Swath: A swath is the data resulting from a single flight line of collection representing the coverage width area across the flight path of the LiDAR sensor.

Tenderloin: This is the central part of the swath that, when combined with adjacent swath tenderloins, forms a complete, single, non-overlapped, gap-free coverage. In collections designed using multiple coverage, tenderloins are the parts of the swath necessary to form a complete non-overlapped, gap-free coverage at the planned depth of coverage.

Triangulated Irregular Network (TIN): A TIN is a vector data structure that partitions geographic space into contiguous, non-overlapping triangles. In LiDAR, the vertices of each triangle are LiDAR points with x, y, and z values. In most geographic applications, TINs are based on Delaunay triangulation algorithms in which no point in any given triangle lies within the circumcircle of any other triangle.

Vertical Accuracy: Vertical accuracy is the measure of the positional accuracy of a data set with respect to a specified vertical datum, at a specified confidence level or percentile. At 95% confidence, vertical accuracy is defined as:

Vertical Accuracy at 95% = 1.9600 x RMSEz

$$RMSE_z = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{i(LiDAR)-} x_{i(Survey)})2}$$

Note that $x_{i(LiDAR)}$ are a set of LiDAR points being evaluated and $x_{i(Survey)}$ are the corresponding survey check points used to compare the LiDAR elevation (z) points at that geographic location. *n* is the number of check points.

- **Vegetated Vertical Accuracy (VVA):** VVA replaces supplemental vertical accuracy (SVA) and consolidated vertical accuracy (CVA). It is an estimate of the vertical accuracy, based on the 95th percentile, in vegetated terrain where errors do not necessarily approximate a normal distribution.
- **Non-vegetated Vertical Accuracy (NVA):** NVA replaces fundamental vertical accuracy (FVA). It is the vertical accuracy at the 95-percent confidence level in non-vegetated open terrain, where errors should approximate a normal distribution.

Vertical Error: This is the displacement of a feature's recorded elevation in a dataset from its true or more accurate elevation, usually recorded as Delta (Z_D) value.

Waveform Data (Full-waveform): This is a LiDAR system or data in which the entire reflection of the laser pulse is fully digitized, captured, and stored. Discrete return point clouds can be extracted from the waveform data during post processing.

Well-distributed: For a dataset covering a rectangular area that has uniform positional accuracy, check points should be distributed so that points are spaced at intervals of at least 10 percent of the diagonal distance across the dataset and at least 20 percent of the points are located in each quadrant of the dataset (adapted from the NSSDA of the Federal Geographic Data Committee, 1998). As related to this specification, these guidelines are applicable to each land cover class for which check points are being collected.

Withheld Points: A withheld points is marked by a single bit flag indicating that the associated LiDAR point is geometrically anomalous or unreliable and should be ignored for all normal processes. These points are retained because of their value in specialized analysis. Withheld points typically are identified and tagged during preprocessing or through the use of automatic classification routines.

8.0 REFERENCES

American Society for Photogrammetry and Remote Sensing (ASPRS), 2014, Positional accuracy standards for digital geospatial data – draft revision 7, version 1: American Society for Photogrammetry and Remote Sensing.

American Society for Photogrammetry and Remote Sensing (ASPRS), 2011, LAS specification version 1.4 – R13: Bethesda, Md., American Society for Photogrammetry and Remote Sensing, 27 p. Available at LASer-LAS-File-Format-Exchange-Activities. Available at http://www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html.

Heidemann, Hans Karl, 2014, LiDAR base specification (ver. 1.2, November 2014): U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 67 p. with appendices. Available at Geological Survey Techniques and Methods - http://dx.doi.org/10.3133/tm11B4.

High Resolution Digital Elevation Model (HRDEM) – CanElevation Series -Product Specification Edition 1, Natural Resource Canada, March 31, 2017. http://open.canada.ca/en/open-maps

Guideline for RTK/RTN GNSS Survey in Canada, Natural Resource Canada, Version 1.1, July 2013. Available at http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/Canada-RTK-UserGuide-v1_1-EN.pdf.

Natural Resources Canada, Canadian Airborne LiDAR Acquisition Guideline, Version 1.0, May 01, 2014.

Ontario Specifications for LiDAR Acquisition version 1.1. Government of Ontario, April 15, 2016.

GEOBC Specifications for LiDAR, version 2.0, Ministry of Forests, Lands and Natural Resource Operation, March 27, 2014.

Nova Scotia LiDAR Data Acquisition and Quality Assurance Specifications Version 1.0, Spatial energistics group April 11, 2012.

Alberta Environment and Sustainable Resource Development, General Specification for Acquisition of LiDAR Data, March 2015.

New Zealand National Aerial LiDAR Base Specification, Land Information New Zealand, December 2016.

National Network of Regional Coastal Monitoring Programmes of England, Specification for LiDAR Surveys Version 1.0 August 2015.

ICSM LiDAR Acquisition Specifications and Tender Template, Australia, Version 1.0, November 2010.

Provision of LiDAR Services for The Government of Manitoba Water Management, Planning and Standards Service Area: Souris River Basin Term: To March 31, 2017.

Province of New Brunswick Draft LiDAR Specifications, Government of New Brunswick, June 2016.

Levés Laser Aéroporté (LiDAR), Traitement et Livraison des Données Classifiées pour des Territoires Situés Dans la Région de L'Abitibi-Témiscamingue, Ministère de L'énergie et des Ressources Naturelles, 13 juillet 2016.

ANNEX A: Forestry

Introduction

Both discrete and full waveform airborne LiDAR data have been used in a range of forest applications, including the generation of forest resource inventories. Forest applications of LiDAR are typically either area-based or at the individual tree level. While the area-based approach is currently considered operational in a forest inventory context, individual tree approaches are emerging. Airborne LiDAR data provides 3D mapping of vegetation structure through the forest canopy and is therefore useful for estimating biophysical parameters such as height, volume, aboveground biomass and to some extent, vegetation density. In addition, airborne LiDAR can indicate the presence or abundance of understory vegetation and the ground surface (for terrain mapping) under forest canopy, which is not achievable by other remote sensing technology. The bare earth Digital Elevation Model referred to as a Digital Terrain Model, derived from LiDAR data has proven very helpful for forest engineering (i.e., optimizing forest road and harvest block layout). The information provided below represents current recommendations regarding acquisition of airborne LiDAR data for forest applications. End users should consider the recommendations below in the context of their specific information needs.

Data Considerations

Collecting and utilizing airborne LiDAR data for forest applications is dependent on the intended project objectives. Requirements should consider the type of terrain, the complexity of the forest characteristics, and the required information (i.e., what parameters are needed?), and forest types (deciduous vs. coniferous). Table A1 provides some guidelines regarding minimum pulse density ranges for different Canadian forest types and measurement.

Table A1. Guidelines for minimum pulse densities depending on application and forest types.

Forest Application	Forest Type Regions[1]	Description	Pulse Density Range
Area Based Approach	Carolinian and Great Lakes – St Lawrence Forest	Area-based mapping of primarily deciduous forest and areas mixed with conifer trees	1 – 4 pls/m^2
	Boreal and Acadian Forest	Area-based mapping of primarily conifer forest with areas mixed with deciduous trees particularly in riparian zones	1 – 4 pls/m^2
	Coast, Montane and Columbia Forest	Area-based mapping of dense forest in high relief areas	6 – 12 pls/m^2

Individual Tree Approach	Carolinian and Great Lakes – St Lawrence Forest	Individual tree mapping of primarily deciduous forest and areas mixed conifer trees	4 – 8 pls/m^2
	Individual tree and estimating tree-canopy attributes within Boreal and Acadian Forest	Individual tree mapping of primarily conifer forest with areas mixed with deciduous trees particularly in riparian zones	6 – 8 pls/m^2
	Coastal, Montane and Columbia Forest	Individual tree mapping of dense forest in high relief areas. Pulse density be higher depending on tree size and density of trees in the stand	6 – 12 pls/m^2

[1] Forest Regions in Canada http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/24040.pdf

- Pulse density is defined by Aggregate Nominal Pulse Density (ANPD) which is a design average or median pulse density that includes inter-swath (overlapping swath) pulses with the exception of acceptable data void areas as defined in the Federal Airborne LiDAR Data Acquisition Guideline.
- The above table represents the acquisition of airborne LiDAR during leaf-on conditions. Flying in the fall or early spring during leaf-off conditions in areas of significant deciduous trees and where understory and other vegetation cover are in a dormant state, can result in more returns from the ground surface, thereby achieving a more accurate terrain characterization. By contrast, acquiring data during leaf-on conditions may enable improved characterization of forest structure, although the requirement for leaf-on or leaf-off data is ultimately dependent on the forest type and the information need. For example, and a summary of other literature please see White et al. (2015).
- When applying an area-based approach for forest attribute modeling, a Digital Terrain Model (DTM) grid of 2 m is suitable. By contrast, when conducting individual tree modeling and modelling areas of complex terrain or supporting the determination of forest roads, a 1 metre grid is recommended.

Acquisition Parameters Considerations

LiDAR sensors can be configured in a manner to optimize for forest applications. Again, the parameters selected for forest applications are dependent on the intended project objectives and associated information needs. Table A2 provides a summary of recommended acquisition parameters based on current scientific knowledge and available sensors.

Table A2. Recommended acquisition parameters for airborne LiDAR for forest applications.

Acquisition Parameters	Recommendation	Description
Laser beam divergence	0.1-0.6 mrad	Laser beam divergence represents the angular spread of the laser pulse which is a combination of the height of the aircraft, scan angle and motion of the aircraft (plus the slope of the terrain) to determine the LiDAR footprint. This assumes the beam divergence defines a LiDAR footprint width of 1/e. Generally, small footprints (< 30 cm) with higher pulse energy are preferred, particular for individual tree feature extraction.
Scan angle	< ±20° is recommended, but even narrower scan angles < ± 15° are desirable for most forest applications	Narrow scan angles increase penetration through the canopy, support smaller footprints, and increase incident pulse energy.
Returns per pulse	Minimum 2 returns per pulse (first and last)	For discrete LiDAR systems, a minimum of 2 returns per pulse is recommended for canopy and ground modeling (first and last returns). While 4 or more returns (first, last and intermediate) per pulse are desired. Waveform data may also be desirable from a research perspective when mapping forest or tree structural features.
Swath overlap	Minimum 20%	Overlap or interswath is used to minimize gaps in data collection from changes in aircraft attitude and topography changes.
Vertical accuracy	+/- 0.3 – 0.5m $RMSE_z$	The range typically used for the vertical accuracy for forest applications.
Horizontal accuracy	+/- 0.5 – 1.0m $RMSE_r$	The range typically used for the horizontal accuracy for forest applications.

- Current LiDAR sensors have high repetition rates sufficient for providing an adequate pulse density. Sensor configuration of repetition rate should be largely determined by flight parameters, design ANPD, scan angle, swath overlap for no gaps and sufficient pulse energy to avoid drop outs.
- Planned LiDAR acquisition parameters should be designed and conducted with no data gaps and no data void areas except in those areas where low near infrared surface reflectance features are present, such as water. The spatial distribution of geometrically usable points will be uniform and regular except for data void areas. A specified minimum pulse density, as recommended in Table A1 or defined by the project objectives, should be present in 90% of cells of a uniform density grid within usable portion of a swath. See the

Section 6.1.1Project Method of the Federal Airborne LiDAR Data Acquisition Guideline for additional details on the acquisition planning considerations.

- A recommended minimum LiDAR point cloud classification will be conducted for forest applications compliant with ASPRS LAS 1.4 – R13 format and specification. Calibrated LiDAR pulses will be classified from Class 0 assigned to Class 7 for low noise, Class 18 for high noise. Class 2 for bare earth ground pulse returns. Outliers, geometrically unstable pulse data, and blunders will be identified using the Withheld Flag and not be used in the classification process. The remaining points will be placed into Class 1 for processed but unclassified. Classification will be consistent across the entire project, void of noticeable variation in character, texture or quality of the classification between tiles, swaths, lifts or other non-natural division. Classification accuracy will be in compliance with the Federal Airborne LiDAR Data Acquisition Guideline in Section 4. Additional classification requirements will be based on project specific requirements this may include Class 3 for low vegetation, Class 4 for medium vegetation, Class 5 for high vegetation and Class 9 for water.

References

Evans, J.S., Hudak, A.T., Faux, R.; Smith, A.M.S. 2009. Discrete Return LiDAR in Natural Resources: Recommendations for Project Planning, Data Processing, and Deliverables. Remote Sensing. 1: 776-794.

Gatziolis, D.; Andersen, H-E. 2008. A guide to LiDAR data acquisition and processing for the forests of the Pacific Northwest. General Technical Report. PNW-GTR-768. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p.

Haugerud, R., Curtis,T., Maddin, I., Martinez, D., Nelson, S., Nile, E., Reutebuch, S. 2008. A proposed specification for LiDAR surveys in the Pacific Northwest. Puget Sound LiDAR Consortium 12 p.

Laes, D., Reutebuch, S.,McGaughey, B., Maus, P. Mellin, T., Wilcox, C., Anhold, J., Finco, M., Brewer, K.. Practical LiDAR acquisition considerations for forestry applications. RSAC-0111-BRIEF1, Salt Lake City, Utah, US Department of Agriculture, Forest Service, Remote Sensing Applications Center, 2008.

McGaughey, R.J., Andersen, H-E., Reutebuch, S.e. "Considerations for planning, acquiring, and processing LiDAR data for forestry applications." In 11th Biennial USDA Forest Service Remote Sensing Applications Conference, Salt Lake City, UT. 2006.

Montaghi, A. 2013. Effect of scanning angle on vegetation metrics derived from a nationwide Airborne Laser Scanning acquisition. Canadian Journal of Remote Sensing,39(s1): S152-S173, DOI: 10.5589/m13-052

Reutebuch, S.E., McGaughey, R.J. 2008. LiDAR: An emerging tool for multiple resource measurement, planning, and monitoring." Western Forester, 53: 1-5.

White, J.C., Arnett, J.T.T.R., Wulder, M.A., Tompalski, P., Coops, N.C. 2015. Evaluating the impact of leaf-on and leaf-off airborne laser scanning data on the estimation of forest inventory attributes with area based approach. Canadian Journal of Forest Research, 45: 1498-1513. https://cfs.nrcan.gc.ca/publications?id=36446

White, J.C., Wulder, M.A., Varhola, A., Vastaranta, M., Coops, N.C., Cook, B.D., Pitt, D, Woods, M. 2013.A best practices guide for generating forest inventory attributes from airborne laser scanning data using an area-based approach. The Forestry Chronicle 89(6): 722–723.

White, J.C., Wulder, M.A., Varhola, A., Vastaranta, M., Coops, N.C., Cook, B.D., Pitt, D, Woods, M. 2013. A best practice guide for generating forest inventory attributes from airborne laser scanning data using the area-based approach. Information Report FI-X-10. Canadian Forest Service, Canadian Wood Fibre Centre, Pacific Forestry Centre, Victoria, B.C. 50 p. English language version: http://cfs.nrcan.gc.ca/publications?id=34887. French language version: http://cfs.nrcan.gc.ca/publications?id=35375

Wulder, M., White, J.C., Nelson, R.F., Næsset, E., Ørka, H.O., Coops, N.C., Hilker, T., Bater, C.W., Gobakken, T. 2012. LiDAR sampling for large-area forest characterization: A review, Remote Sensing of Environment, 121: 196-209.

ANNEX B: Floodplain Mapping

Introduction

LiDAR data is considered to be the primary source of Digital Elevation Model (DEM) data for various floodplain mapping applications, including specialized technical products such as inundation, flood hazard or flood risk maps, as well as public information maps. The primary goal of LiDAR applications in floodplain mapping is to obtain accurate elevation data, which are required for both the hydraulic modelling (deriving water elevations and extents for floods of various magnitudes) and the cartographic components of floodplain mapping projects. The elevation datasets include:

- Ground elevation data, which is built from last LiDAR returns, contains only topography, and is usually referred to as the Digital Terrain model (DTM)
- First return elevation data, which is built from first returns and includes structures (e.g. buildings and bridges) and tree canopy, and is usually called the digital surface model (DSM).

Another use of LiDAR data is to facilitate floodplain characterization, i.e. extraction of planimetric or basemap features useful for guiding hydraulic modelling and for creating floodplain maps, such as roads and pavement areas, stream banks, bridges, ditches, etc. Floodplain characterization is best accomplished using LiDAR in combination with orthophotos. The level of detail in floodplain characterization should be appropriate for the scale of the intended floodplain mapping (e.g. higher detail will be required for 1:2,000 scale maps compared to 1:5,000).

Data Acquisition Considerations

Low Flow Conditions

In addition to the environmental conditions typically recommended for LiDAR data collection (no snow or ice on the ground, shorelines and water courses free from significant ice buildup, no unusual flooding or inundation), LiDAR collection for floodplain mapping should take place during base flow (dry) conditions to maximize the area of water courses exposed; thus, maximizing the utility of the collected data for hydraulic modelling.

Stable Flows and Levels

Flow and levels in the water courses and water bodies should remain stable, i.e. free of significant fluctuations throughout the data collection period to maximize consistency of collected data. This is important in situations where water flows/levels are prone to rapid changes, e.g. rivers with flashy response or regulated rivers. When data collection spans a significant length of time (usually due to a large size of data collection area, which could potentially require data acquisition during several seasons), preference should be given to data collection during similar flow/level conditions.

Leaf-off Conditions

Leaf-off conditions are recommended to maximize canopy penetration thus maximizing ground point density and the quality of the resulting DTM. However, leaf-off acquisition is not required as long as the point density and vertical accuracy of non-canopy returns are sufficient to meet DTM and DSM accuracy requirements. In some cases leaf-on acquisition may be preferred or necessary to map and characterize vegetation types, for example for hydrological or detailed hydraulic (e.g. estimation of Manning’s n) modelling.

Acquisition Parameters

Table B1 summarizes the minimum required and recommended LiDAR acquisition parameters for floodplain mapping applications. Higher swath overlap is recommended for areas of high relief terrain.

Table B1. Minimum required and recommended LiDAR acquisition parameters for floodplain mapping applications.

Acquisition Parameter	Minimum	Recommended
Swath overlap – overlap between geometrically usable portions of swaths (typically 95% of swath width)	20%	50%
Field of view (FOV)	± 25 degrees from nadir	± 20 degrees from nadir
Number of returns	≥ 2	>3
Intensity	Yes	Yes

Orthophoto Acquisition

Aerial images, particularly orthophotos, are extremely useful for floodplain mapping, providing valuable information for hydrologic, hydraulic and risk analyses, as well as a very useful basemap dataset for all types of floodplain maps. Orthophotos are also invaluable for hydro-enforcement of DTM, which is a recommended practice for post-processing LiDAR-derived DEMs (see below). If sufficiently high-quality and up-to-date orthophotos are unavailable for the planned LiDAR data collection area, consideration should be given to acquisition of orthophoto data within the same time frame as LiDAR to maximize data usability for floodplain mapping.

Data Quality Considerations

Data Density and Accuracy

Floodplains can have a variety of land cover types from open to low vegetation, brushland, forested or urban. Acquisition of LiDAR data in the floodplain is therefore subject to a variety of conditions and should ultimately be guided by the need to collect sufficient ground returns for all cover types present in the floodplain. For example, if a portion of the data collection area is covered in dense riparian vegetation, higher overall data collection density may be required in order to achieve sufficient ground point density in the riparian area.

The level of data collection effort (point density, vertical and horizontal accuracy) should generally reflect the requirements of the intended flood mapping application, which typically depend on the level of flood risk and the regulatory framework in place. Table B2 lists the recommended approximate LiDAR data accuracy and density specifications for floodplain mapping applications as a function of flood risk category, based on the review of existing provincial and territorial guidelines (Alberta Environment, 2011; Kerr Wood Leidal, 2011; Spatial Energistics Group, 2012; Elevation Coordination and Consultation Committee, Government of Ontario, 2016) and the National Floodplain Mapping Assessment report by MMM Group Limited (2014). The flood risk categories are defined following the MMM report, and are similar to the vertical accuracy classes adopted in the Ontario guidelines:

- High Flood Risk Category: All urban areas and rural areas that are protected by diking;
- Medium Flood Risk Category: All other rural areas that include settlements and agricultural lands;
- Low Flood Risk Category: Sparsely populated areas.

Table B2. Recommended approximate LiDAR data accuracy and density for floodplain mapping applications.

	Flood Risk Category		
	High	**Medium**	**Low**
Vertical Accuracy (open, level, hard surfaces)			
Non-vegetated Vertical Accuracy (NVA) – Vertical Root Mean Square Error ($RMSE_Z$)	≤ 5.0-7.5 cm	7.5-10.0 cm	15 cm
Non-vegetated Vertical Accuracy (NVA) – 95% confidence level (≈ 1.96 * $RMSE_Z$)	≤ ±10-15 cm	±15-20 cm	±30 cm
Horizontal Accuracy (open, level, hard surfaces)			
Horizontal Root Mean Square Error ($RMSE_r$)	≤ 11-15 cm	30-45 cm	60 cm
Horizontal Accuracy – 95% confidence level (≈ 1.7308 * $RMSE_r$)	≤ ±20-25 cm	±50-75 cm	±100 cm
Data Density			
Aggregate nominal point density (ANPD) for DSM (first return) and DEM (last return)	≥ 4-10 pts/m^2	2-4 pts/m^2	1-2 pts/m^2

Classification

The minimum required classes include ground, non-ground and water, which are necessary for creating and hydro-enforcing the DTM. Buildings and other man-made structures class(es) will also typically be required to create a DSM, as well as to facilitate the removal of the building/structures returns from the DTM. It is recommended that the DTM should have at least 90-95% of buildings and structures removed. In addition, vegetation classes may be necessary in some cases for hydrotechnical modelling and base mapping.

Hydro-flattening

Hydro-flattening is a post-processing method applied to LiDAR-derived DEMs to ensure that water surfaces are flat in the bank-to-bank (perpendicular to the apparent direction of flow) direction, and non-increasing in the downstream direction. In some cases, further hydrological enforcement may be required for drainage features and flat river area with islands/channels where 2D flows may occur. Hydro-flattening is a recommended floodplain mapping application, the specific guidelines and specifications would be defined by the contracting authority

Other Considerations

Topo-bathymetric LiDAR

Consideration may be given to utilizing topo-bathymetric LiDAR systems for simultaneous and seamless collection of topographic and bathymetric data. Traditional methods for collecting bathymetric data (underwater portion of the river channel geometry), which involve echo sounding devices on boats or manual surveying, are expensive, time consuming and potentially hazardous. Topo-bathymetric systems include a green laser for penetrating the water and measuring the bathymetry and are able to generate a seamless above/below water elevation data. Details on using topo-bathymetric LiDAR will be included in future version of this guideline

References

Alberta Environment, 2011. Flood Hazard Identification Program Guidelines. Alberta Environment, Water Management Operations, River Forecast Section, 92 p.

American Society for Photogrammetry and Remote Sensing (ASPRS), 2014. Positional accuracy standards for digital geospatial data, Edition 1, Version 1.0: American Society for Photogrammetry and Remote Sensing, 26 p., http://www.asprs.org/wp-content/uploads/2015/01/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf

Federal Emergency Management Agency (FEMA), 2016. Guidance for Flood Risk Analysis and Mapping, Elevation Guidance (May 2016): Federal Emergency Management Agency, 21 p.

Heidemann, Hans Karl, 2014. LiDAR base specification (Version 1.2, November 2014): U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 67 p. with appendices, http://dx.doi.org/10.3133/tm11B4. ISSN 2328-7055.

Kerr Wood Leidal, 2011. Coastal floodplain mapping – guidelines and specifications. Prepared for the Ministry of Forests, Lands and Natural Resource Operations, Government of British Columbia, 91 p.

Mapcon Mapping Ltd., 2009. Imagery and Elevation Acquisition Guidelines, Version 1.2. Prepared for the Government of Ontario, 18 p.

MMM Group Limited, 2014. National Floodplain Mapping Assessment, Final Report. Prepared for Public Safety Canada.

Natural Resources Canada, 2014. Canadian Airborne LiDAR Acquisition Guideline, Version 1.0, May 01 2014, 26 p.

Elevation Coordination and Consultation Committee, Government of Ontario, 2016. Ontario Specifications for LiDAR Acquisition, Version 1.1, 2016-04-15.

Spatial Energistics Group, 2012. LiDAR Data Acquisition and Quality Assurance Specifications, version 1.0. Prepared for Department of Fisheries and Aquaculture, Government of Nova Scotia, 61 p.

ANNEX C: High Relief Terrain

Introduction

Conducting topographic mapping and/or forest inventory in high-relief terrain areas using airborne LiDAR data requires an adjusted approach to data collection. High relief areas are typically mountainous areas where steep slopes occur e.g. > 35 degree and there is significant altitude change that results in implications to LiDAR collection e.g. surface conditions due altitude temperature difference or impacts on flying parameters due to terrain characteristics. High relief areas complicate typical data collection due to a mix of undulating terrain, steep slopes, remote access, and environmental conditions. The intent of this section is to provide recommendations and considerations when collecting airborne LiDAR data in high-relief areas.

Table C1. Recommended collection parameters.

Parameter	Condition	Description
Scan Angle	Select narrow scan angles ≤ ±15◦	The rapid surface slope changes in mountainous terrain can elongate laser pulses footprints and have a more pronounce effect on vertical features such as trees. The steep slope also increases positional uncertainty at swath edges. Narrow scan angels minimize this effect and provide improved mapping of trees in mountainous areas.
Overlap	50% recommended	Changing terrain increases the potential for data gaps. Higher overlap between flights lines minimizes gaps in the data and increases ground penetration in high relief terrain.
Pulse Repetition Frequency (PRF)	Lower to increase pulse return energy and less drop out.	Steep slope and uneven terrain increases LiDAR pulse scattering away from the receiving sensors resulting shot drop out. Lower PRF increases transmitted pulse energy, potentially lowering pulse drop out. In addition, aircraft can fly higher, increasing safety margin.
Collection Conditions	At altitude, surface snow persist longer and terrain can create higher wind turbulence	Snow on the ground at higher altitudes remains longer than at lower elevation. The window of data collection is narrower and planning should consider the impact of extended surface snow period at altitude. Also, terrain characteristics may increase air turbulence in the data collection area. This will impact the quality of the data including increase potential of data gaps due to aircraft rolling to compensate for windy conditions.

Positioning	GNSS signal loss	Aircraft and in-situ check point measurements using GNSS receivers may be impacted by terrain blockage. Terrain may impact the PDOP value reducing the number of visible satellites and the determination of position. Ground base station baseline distance is recommend at 25-30km
Flight Lines	Adjust flight block size and orientation	Flight planning should consider terrain characteristics including orientation and sizes of flight blocks for creating even swath areas and pulse density distribution. Smaller block sizes are recommended.
Remote Access	Difficulty collecting Checkpoints	High-relief areas present challenges for in-situ checkpoint collection. Access can be difficult and may limit the number of checkpoints.

References

Evans, Jeffery, S., Hudak, Andrew, T., Faux, Russ, and Smith, Alistair, M.S. Discrete Return LiDAR in Natural Resources: Recommendations for Project Planning, Data Processing and Deliverables. Remote Sens. 1, 776-794, 2009.

Hirata, Y. The Effect of Footprint Size and Sampling Density In Airborne Laser Scanning To Extract Individual Trees in Mountainous Terrain. International Archives of Photogrammetry, Remote Sensing and Spatial Information Science, Vol. XXXVI-8/W2.

Hopkinson, Chris, Demuth, Mike, Sitar, Mike, and Chasmer, Laura. Application of Airborne LiDAR Mapping in Glacierised Mountainous Terrain. Geoscience and Remote Sensing Symposium, 2001. IGARSS '01. IEEE 2001 International.

Hsu, Wei-Chen, Wu, Li-Wei, and Liu, Jin-King. Airborne LiDAR Survey in Cloudy and Extremely High Relief Mountainous Terrain of Taiwan. IGARSS 2012.

Jordan, Thomas, Marguerite Madden, Byungyun Yang, J. Sharma, and Sudhanshu Panda. "Acquisition of LiDAR for the Tennessee Portion of Great Smoky Mountains National Park and the Foothills Parkway." Center for Remote Sensing and Mapping Science (CRMS), Department of Geography, The University of Georgia, Athens, Georgia, USA, Tech. Rep. USGS Contract (2011).

Mitchell, Brent, Mike Walterman, Tom Mellin, Craig Wilcox, Ann M. Lynch, John Anhold, Donald A. Falk et al. "Mapping vegetation structure in the Pinaleno Mountains using LiDAR-phase 3: Forest inventory modeling." (2012).

Su, Jason, and Bork, Edward. Influence of Vegtation, Slope and LiDAR Sampling Angle on DEM Accuracy. Photogrammetric Engineering & Remote Sensing Vol 72, No 11, pp 1265-1274, 2006.

ANNEX D: Urban Infrastructure Mapping

Introduction

The advancements in airborne LiDAR technology provide a multidimensional data source for 3D mapping at finer precision for urban environments. LiDAR applications for cities include mapping building features, urban forestry, defining floodplain areas, utility feature extraction, land cover classification and corridor assessment to name a few. Adjustments to LiDAR data collection and processing are needed to accommodate the variation in the urban landscape. This guideline aims to provide general guidance for LiDAR data collection for different types of urban applications.

Data Collection Considerations

Table D1 is general data collection consideration and recommendations for collecting in urban environments.

Table D1. Collection considerations.

Items	Description
Conditions	The collection of LiDAR data for urban infrastructure is desirable to be acquired under leaf-off conditions except for the applications of urban forestry. This increases exposure to ground, building rooftops and distribution wires. Other collection conditions as specified in Section 4 would be recommended.
Swath Overlap	This should be no less than 50% of the swath overlap to minimize voids, building shadowing or surface areas with little to no near infrared reflectivity such as asphalt.
Scan Angle	Narrow scan angles ≤ 40 degrees Field of View (+/- 20 degrees from the nadir) to minimize occluded areas.
Accuracy Requirements	Typical urban applications of LiDAR technology would desire pulse data vertical accuracy within open areas ≤15cm at 95% and horizontal accuracy ≤40cm at 95%.
Pulse Footprint	Small foot prints are preferred for detecting edges of objects.
Return	Multiple discrete returns are usually required, at least first and last returns. Intermediate pulses are beneficial for tree/forestry applications, multiple wires and building edges.
Flight Orientation	Depending on the orientation of roadway, flight lines perpendicular to road orientation for cities dominated by rectilinear grid roads would be preferred. Furthermore to minimize occluded areas, flights could be orientated for both parallel and perpendicular lines. However, this would require additional cost due to increase flying requirements.

Data Processing Considerations

The LiDAR data acquisition process should include intensity image, point cloud classification and digital surface models. Digital surface models for cities include Digital Elevation Models with appropriate breaklines and hydro-flattening, Digital Surface Model and Canopy Height Model. Additional point cloud classification of pulse data base LAS 1.4 – R13 classification in the Table A2 would depend on project specific requirements but may include features such as rails, road surface, wires, and vegetation. Additional classes that could be assigned to class 64-255 for urban environments includes, light poles, road markings, street car tracks, electrical distribution poles, sidewalks, parking lots, and trails.

Table D2. LAS 1.4 Classification.

Class	Description
0	Created, never classified
1	Unclassified
2	Ground
3	Low Vegetation 0-0.3m
4	Medium Vegetation 0.3-2.0m
5	High Vegetation 2m
6	Building
7	Low Point (noise)
8	Reserved
9	Water
10	Rail
11	Road surface
12	Reserved
13	Wire – Guard (Shield)
14	Wire – Conductor (Phase)
15	Transmission Tower
16	Wire Structure Connector (e.g. Insulator)
17	Bridge Deck
18	High Noise
19-63	Reserved
64-255	User Definable

Pulse Density for Feature Extraction

The table below represents recommended LiDAR pulse density ranges (ANPD) for various urban applications for feature extraction. General recommendation for urban mapping is for a pulse density ≥ 10 pls/m^2, however depending on project specific objectives, the pulse density may range to accommodate the type of feature extraction. Table A3 provides a recommend range of ANPD for different types of feature extraction.

Table D3. Pulse Density Ranges for Feature Extraction.

Application	Data Collection	Data processing
Building Footprint Extraction	8 - 15 pls/m^2	Building footprint extraction depends on the desired level of detail of the structure and the physical spacing between the buildings and roof features. In developed urban environments, higher pulse density is preferred with small pulse footprints to accurately define building edges, gaps between buildings and roof characteristics. Intermediate pulses may be beneficial for refining building edges.
Land Cover	5 - 10 pls/m^2	General urban land cover classification using LiDAR data requires sufficient pulse density to separate different land cover features. In cites, land cover types change rapidly and detecting small land cover types requires higher pulse densities.
Terrain	4– 15 pls/m^2	Mapping urban topography requires sufficient spatially distributed pulse density to extract ground features. The pulse density is dependent on the complexity of the terrain and accuracy required.
Utility and Corridor Mapping	10 – 25 pls/m^2	The mapping of utility wires, light poles, road marks and signs requires high pulse density with narrow footprints at regular short pulse spacing; whereas, intermediate pulse return may be desirable for mapping poles with multiple wires.
Individual Trees	4 - 12 pls/m^2	Tree modeling requires a higher pulse density than forest area mapping and requires a smaller footprint size.
Forest Area	2 – 4 pls/m^2	This is adequate for canopy height modeling and bare earth returns.
City 3D Model	6 – 20 pls/m^2	The pulse density for generating DSM, DEM, Classified point clouds depends on the application of the model.

Considerations, Limitations and Assumptions

- Acquisition of airborne LiDAR data in urban areas may be performed during day or night and may be restricted due to air traffic control limitations. Planning for data collection should consider impacts to scheduling due to limitations in collecting the data near airports.
- In urban areas, certain building heights and structures can contribute significantly to LiDAR shadows and occlusions, which can cause a large number of data gaps in the LiDAR point cloud. From this perspective, multiple angles or narrow FOV of LiDAR systems may be necessary for urban applications. The decision should provide a balance between the building density, height and road network orientation in conjunction with financial considerations.
- In mapping buildings and the distribution of power lines, these may be obscured by trees; therefore, they may not be fully extracted from LiDAR data. Leaf off conditions can improve the detection of these features.
- Some building roofs and walls are made of glass which may be transparent or semitransparent. Consequently, there is a significant number of unexpected LiDAR points reflected from objects inside the building and under the rooftop. Many of these points may be considered as noise; thus, classified point clouds should take noise class into account.

References

Alexander, Cici, Kevin Tansey, Jörg Kaduk, David Holland, and Nicholas J. Tate. "Backscatter coefficient as an attribute for the classification of full-waveform airborne laser scanning data in urban areas." ISPRS Journal of Photogrammetry and Remote Sensing 65, no. 5 (2010): 423-432.

Awrangjeb, Mohammad, Chunsun Zhang, and Clive S. Fraser. "Automatic extraction of building roofs using LIDAR data and multispectral imagery." ISPRS Journal of Photogrammetry and Remote Sensing 83 (2013): 1-18.

Awrangjeb, Mohammad, and Clive S. Fraser. "An automatic and threshold-free performance evaluation system for building extraction techniques from airborne LiDAR data." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 7, no. 10 (2014): 4184-4198.

Awrangjeb, Mohammad, Guojun Lu, and C. Fraser. "Automatic building extraction from LiDAR data covering complex urban scenes." The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 40, no. 3 (2014): 25.

Clode, Simon, Peter J. Kootsookos, and Franz Rottensteiner. "The automatic extraction of roads from LIDAR data." In The International Society for Photogrammetry and Remote Sensing's Twentieth Annual Congress, vol. 35, pp. 231-236. ISPRS, 2004.

Dorninger, Peter, and Norbert Pfeifer. "A comprehensive automated 3D approach for building extraction, reconstruction, and regularization from airborne laser scanning point clouds." Sensors 8, no. 11 (2008): 7323-7343.

Hu, Xiangyun, Yijing Li, Jie Shan, Jianqing Zhang, and Yongjun Zhang. "Road centerline extraction in complex urban scenes from LiDAR data based on multiple features." IEEE Transactions on Geoscience and Remote Sensing 52, no. 11 (2014): 7448-7456.

Jarzabek-Rychard, M., and H. G. Maas. "Aerial image based geometric refinement of building models derived from airborne LiDAR data." (2016).

Jwa, Yoonseok, and Gunho Sohn. "A piecewise catenary curve model growing for 3D power line reconstruction." Photogrammetric Engineering & Remote Sensing 78, no. 12 (2012): 1227-1240.

Li, Zhengrong, Troy S. Bruggemann, Jason J. Ford, Luis Mejias, and Yuee Liu. "Toward automated power line corridor monitoring using advanced aircraft control and multisource feature fusion." Journal of Field Robotics 29, no. 1 (2012): 4-24.

Marks, Kate, and Paul Bates. "Integration of high-resolution topographic data with floodplain flow models." Hydrological Processes 14, no. 11-12 (2000): 2109-2122.

McLaughlin, Robert A. "Extracting transmission lines from airborne LIDAR data." IEEE Geoscience and Remote Sensing Letters 3, no. 2 (2006): 222-226.

Meesuk, Vorawit, Zoran Vojinovic, Arthur E. Mynett, and Ahmad F. Abdullah. "Urban flood modelling combining top-view”.

Yan Wai Yeung, Shaker Ahmed, and El-Ashamwy Nagwa. “Urban land cover classification using airborne LiDAR data: a review.” Volume 158, 1 March 2015, Pages 295-310.

ANNEX E: Contract

The guideline reflects specifications for collecting airborne LiDAR data and contracts identify specific requirements, enhancements or changes to the guidelines. Key contract items included are listed below.

Definitions

Include a reference list of terms used in contract with definition.

Vendor Information

Provide information about the vendor including legal name, operational centre, contact information.

Scope

Project specific requirements would be specified in this section. They would include data requests such waveform data, increase quality assurance where the vendor requires more sampling, and higher pulse density. A schedule and detailed deliverables would be clearly listed.
Some specific project scope contract items to be consider by the contracting authority are as follows:

- DCAOI
- Pulse density required
- Review of methodology
- Deviation from instrumentation
- Vertical and horizontal accuracy
- Request for intermediate or waveform pulse data
- Data collection period
- Check points consideration including the number and who will conduct this
- Data ownership and usage
- Contingency plan
- Time period for data validation and verification on project deliverables
- Raw data requirements
- Additional post classification fields
- Any derivative products i.e. DEM, contours, hydro-flattening
- Tile sizes, file format and naming convention
- Waivers or adjustment for high relief areas, snow and vegetation conditions
- Accepting compress LAZ files
- Use of Virtual Reference Systems
- Number of classification check
- Conditions for rejecting the data e.g. data voids or density

Insurance

Insurance coverage for aircraft and automobile is required. This would include Commercial General Liability and Errors and Omission. Specific liability amount would be identified. The contract authority would be identified as rider on the insurance.

- Confirm Insurance coverage and requested certificate
- Confirm Workplace Safety Insurance Coverage

Safety

Workplace safety plan would be provided to ensure the safety in data collection particularly in remote locations. This would include identification of hazards, risk assessment, mitigation plan and required safety gears. Safety consideration must follow all federal and provincial government regulations. Examples include: vehicle roadside safety, hours of data collection and wildlife hazards.

- Request vendor health and safety plan

Termination Clause

Identify the conditions where a vendor fails to perform duties or breaches contract. A termination clause would be included in the contract identifying conditions for termination.

Dispute Resolution

Should a dispute in the terms and condition of the requirements and contract occur, this section would cover a detailed process for dispute resolution including notification by vendor or contracting authority, mediation and actions that can be taken.

Wavier

Any exceptions or adjustments by the contracting authority with the terms and conditions of the contract and data collection requirements are to be put into writing to be valid.

Deliverable Review Period

The vendor will provide as part of its deliverable early in the project a plan with methodology for meeting the guideline with respect to data collection, processing and deliverables. A time period is required for the review of the processing and to inspect and accept the deliverables. Terms would be included and a completion certificate for accepted work would be submitted by the vendor.

Payment Terms

Financial payments for the project would consider the upfront costs for airborne operations and the deliverables. Milestone payment and percentage of payment would be structured in the contract. Any withholding would be identified.

Subsuppliers and Subcontractors

Any additional changes of subsuppliers and subcontractors would require written consent by the contract authority for any changes. Workplace safety and all insurance requirements must be enforced with subsuppliers and subcontractors.

Force Majeure

A description outlining a breach of contract due to events such as war, riot, fire, sabotage, national security and other events or circumstances which are not reasonably foreseen and which have not been caused by an act, omission or negligence and is beyond the control of the vendor or contracting authority is included and what conditions and notification would transpire.

Entire Agreement

The contract is to contain all conditions, requirements and specifications. No other terms, agreements or conditions shall be binding.

Performance of Services

A clause indicating time of essence and agreement to perform the required task with the agreed schedule. The contracting authority may terminate the contract upon a default of agreed upon conditions.

Permits

A clause identifying any permits for flying, ground access or other requirements to provide the service and products is required by the Vendor at its own cost.

Compliance with Law

A clause is placed to bind the vendor and any subcontractors, agents, contractors to comply to all applicable laws and regulations at all levels of government. Vendor also indemnify the contract authority from any negligence occurring on behalf of the Vendor, its agents, contractors and subcontractors.

Expediting

A clause may be placed to expedite work and delivery of product should it become apparent that the schedule will not be met.

Warranty

Any warranty with the deliverables shall be provided. Warranty will cover compliance with specifications, quantity and quality. The warranty shall have a period of time and period in which non-conformity would be rectified. The warranty clause may contain any potential liability arising from defected product.

Governing Laws

The laws in which the contract applies can be provincial, federal and/or international laws.

Indemnity

The contract would contain clauses with respect to indemnification arising from not performing the service or delivering the product or negligence in the operation of collecting the data or any other breach of contract.

Confidentiality

Information provided to the vendor by the contracting authority identified as confidential information shall protect the information from unauthorized use, disclosure and duplication of content.

Successors and Assignments

A clause would restrict a vendor from transferring the contract to another party without the consent of the contracting authority. The clause would stipulate the contracting authority’s rights to accept or deny the request.

Data Ownership

This designates the assignment of rights and ownership of the data to the contracting authority. The data ownership model determined between the contracting authority and vendor is on a project by project basis.