A proposed specification for lidar surveys in the Pacific Northwest

by

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Introduction

Recent years have seen the purchase of an increasing number of lidar surveys by public agencies in the Pacific Northwest. Uses for the resulting data include critical-areas regulation, emergency planning, fire modeling, fish habitat analysis and management, flood-plain management, forest engineering, forest inventory, geologic mapping, ground-water modeling and management, highway planning, landslide and seismic hazards investigations, tsunami run-up modeling, and urban and suburban infrastructure engineering.

In this document we propose a common specification for public-agency lidar surveys. A common specification will ease the writing of lidar acquisition contracts, facilitate the sharing of lidar data across agencies, increase the overall usability of lidar data, and minimize cost to the public. While lidar surveys can be designed for different resolutions, accuracies, and costs to meet particular needs, the likely benefits from acquisition of data suitable for multiple uses far outweigh any short-term savings from acquisition of less accurate or lower resolution data.

We seek to specify data with enough accuracy and resolution that repeated surveys can reliably detect landscape changes over short time periods. We thus expect to encourage a continuing market for repeat surveys.

THIS SPECIFICATION DOES NOT REPRESENT POLICY FOR ANY OF OUR AGENCIES. We propose it in the hope of encouraging regional cooperation and discussion. Perhaps at some future time an outgrowth of this specification may become policy.

Writing lidar survey specifications presents a challenge. Good specifications are such that (1) conformance to specifications can be readily evaluated and (2) if data conform to specifications, the data are assured of being suitable for the task at hand. Absolute vertical accuracy, typically the *sine qua non* of topographic surveys, fails this challenge on both counts. Lidar data should be complete, accurate, and usable. We propose specifications that describe these qualities and for which conformance can, with a few exceptions, be easily measured. In general, these specifications focus on lidar data, not the procedures employed to collect the data. An exception is GPS practice, where as contracting entities we have found that it is very expensive to adequately judge the quality of ground control points and absolute spatial positioning; for this reason, we specify some aspects of GPS procedures.

This specification is based on experience with several contractors and multiple contracts, largely in the Pacific Northwest. While it is very much informed by the experience some of us have had with the Puget Sound Lidar Consortium, it is not based solely on this experience. The specification reflects our perception of lidar technology and market conditions as of mid-2007. It should evolve with increasing experience and changing technology. We know that in at least one key aspect (return classification) the specification is deficient.

This specification is designed for the Pacific Northwest. It reflects the prevalence of young, angular landscapes, the regional importance of forests and fish habitat, and the need to intelligently guide ongoing urbanization. It may, perhaps with adjustments, be useful elsewhere.

Lidar survey specifications

Data Acquisition	
Returns per pulse	Lidar instrument shall be capable of recording at least **3** returns per pulse, including 1st and last returns
On-ground laser beam diameter	Between 10 cm and 40 cm
Scan angle	**≤ ±20 degrees**
Swath overlap	Nominal 50% sidelap on adjoining swaths, i.e., survey shall be designed for 100% double coverage at planned aircraft height above ground
Design pulse density	**≥ 4 pulses/m^2** (includes swath overlap; e.g., with 50% sidelap, ≥ 2 pulse/m^2 in each swath) [Note: Higher point densities lead to better description of forest canopy and the built environment, increased chance of obtaining ground returns in forested areas, and greater confidence in identifying ground returns in forested areas.]
GPS procedures	See ***GPS procedures***, below
Survey conditions	Leaf-off and no significant snow cover, as observed by contracting agency. [Note: It can be nearly impossible to meet these conditions in higher-altitude areas with persistent winter snow cover. For these areas, survey conditions may be relaxed at the discretion of the contracting agency.]
Accuracy [Note: Because errors related to dense forest cover are outside the contractor's control, this contract includes no specification for the accuracy of ground-surface (bare-earth) DEMs. The error of a bare-earth DEM includes errors in classifying points as ground and errors introduced by interpolation from scattered ground points to a continuous surface, as well as lidar measurement errors. Analyses of swath-to-swath ground-surface reproducibility suggest that, barring wholesale translation, errors of bare-earth DEMs produced by surveys of western Washington and northwest Oregon are circa 1.5 - 2 times the between-swath reproducibility.]	
Absolute lidar measurement accuracy as verified by contracting agency	**≤ 20 cm** vertical (RMSE) for project as a whole, measured on planar, near-horizontal surfaces [Note: Evaluated using available ground control points (GCPs). Number of available GCPs in a survey area is commonly small thus this requirement is evaluated as $\text{RMSE} \leq \mathbf{20\ cm} * (((n-1) - 2.326 * (n-1)^{1/2}) / n)^{1/2}$ where **n** is the number of GCPs.]
Absolute lidar measurement accuracy as reported by contractor	**≤ 15 cm** vertical (RMSE), measured on planar, near-horizontal surfaces. See ***GPS procedures***, below
Intra-survey reproducibility	Barring true surface change (e.g., tides, changes in river level, active construction, moving vehicles), **≤ 10 cm** vertical (RMSE) for project as a whole **≤ 40 cm** horizontal (RMSE) for project as a whole Within any 500m x 500m area, **≤ 20 cm** vertical (RMSE) on near-horizontal surfaces [Note: Extensive swath overlap allows for robust estimation of intra-survey reproducibility.]
Reproducibility of range measurements	Within any 10m x 10m area, **≤ 5 cm** (RMSE) [Note: Evaluated by measuring departures from planarity of single-swath 1st returns from hard planar surfaces, e.g., building roofs.]

Completeness [Note: Local relief, turbulence, and inability to maintain an exact flying height routinely lead to departures from survey design. For this reason minimum acceptable swath overlap and aggregate 1st-return density are specified here. Data will routinely be evaluated for completeness.]	
Coverage	No voids between swaths. No voids because of cloud cover or instrument failure.
Swath overlap	≤ **20%** no-overlap area per project. No arbitrary 1 km x 1 km square with ≥ **50%** no-overlap area
Aggregate 1st return density	Barring non-scattering areas (e.g., open water, wet asphalt): For entire project area, ≥ **85%** design pulse density Within any 30m x 30m area within areas of swath overlap, ≥ **50%** design pulse density
Spatial Reference Framework	
Vertical Datum	NAVD88, using latest geoid model available from the National Geodetic Survey, unless otherwise specified
Horizontal Datum	NAD83
Projection	UTM, State Plane, or Oregon Lambert (as requested)
Units	Meters (UTM) or survey/international feet (State Plane, Oregon Lambert)
Deliverables	
Report of Survey	Text report that describes survey methods; results; contractor's accuracy assessments, including internal reproducibility and absolute accuracy; file formats; file-naming schemes; tiling schemes. *.pdf, .doc, or .odt format*
Aircraft trajectories (SBET files)	Aircraft position (easting, northing, elevation) and attitude (heading, pitch, roll) and GPS time recorded at regular intervals of 1 second or less. May include additional attributes. *ASCII text or shapefile+.dbf format*
All-return point cloud	List of all valid returns. For each return: GPS week and GPS second OR Posix time, easting, northing, elevation, intensity, return#, return classification. May include additional attributes. No duplicate entries. Time shall be reported to the nearest microsecond or better. Easting, northing, and elevation shall be reported to nearest 0.01 m (nearest 0.01 ft). Classification of returns shall be as complete as is feasible and without avoidable return misclassification. *ASCII text, LAS 1.1 and ASCII text, or LAS 2.0. ASCII files shall have an initial line that lists the fields in the following lines.* *1/100th USGS 7.5-minute quadrangle (0.75 minute by 0.75 minute) tiles; see* ***Tiling scheme****, below* [Note: LAS 1.1 format does not record GPS week. For this reason, ASCII text files are also required. If a survey takes place within a single GPS week, or if the GPS week can be encoded within the LAS record structure in a user field, LAS 1.1 files alone are acceptable. LAS1.1 files shall have all fields populated. LAS 2.0 format provides for GPS week and GPS second or Posix time and this is acceptable. LAS 2.0 files shall include all return attributes identified above.] [Note: Conformance to return classification requirement will be evaluated by visual inspection of large-scale shaded-relief images of ground surface model. See ***Return classification***, below.]
Ground (bare-earth) surface model	Raster of ground surface, interpolated via triangulated irregular network from identified ground points.

	ESRI floating point grid, 6 ft or 3 ft (2m or 1m) cell size, snapped to (0,0), $1/4^{th}$ USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles; see ***Tiling scheme****, below* [Note: Idealization of the landscape in the course of constructing surface models should be avoided. In particular, the triangulated irregular networks from which ground surface raster models are interpolated should not include breaklines derived from other data sources. Such breaklines are typically substitutes for insufficiently dense lidar data.]
Surface models shall have no tiling artifacts and no gaps at tile boundaries. Areas outside survey boundary shall be coded as NoData. Internal voids (e.g., open water areas) may be coded as NoData.	
Formal metadata	See ***Instructions on formal metadata***, below.
Optional Deliverables	
First-return (highest-hit) surface model	Raster of first-return surface, cell heights are highest first return within that cell, cells without first returns shall be coded as NoData *ESRI floating point grid, 6 ft or 3 ft (2m or 1m) cell size, snapped to (0,0), $1/4^{th}$ USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles; see* ***Tiling scheme****, below*
Ground point list	List of X,Y,Z coordinates of all identified ground points. *ASCII text.* *$1/4^{th}$ USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles; see* ***Tiling scheme, below*** [Note: This data layer is a great convenience for CAD users.]
Intensity image	Raster image of 1st-return intensity *TIFF, 3 ft (1m) pixel size, $1/4^{th}$ USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles; see* **Tiling scheme***, below*
Contours	2-ft contours *AutoCAD .dxf or ESRI shapefile format* *$1/4^{th}$ USGS 7.5-minute quadrangle (3.75 minute by 3.75 minute) tiles; see* ***Tiling scheme****, below*
Usability	
Files shall be named as described in ***File names***, below	
Files shall have consistent internal formats	
Contractor shall propose all details of file names and file formats that are not specified here. Proposed names and formats must be approved by contracting agency	
Files may be gzip or zip compressed. Use of compression shall be uniform across a given data layer	
GIS data (ESRI grids, shapefiles) shall have complete and correct associated projection files	
All files must be readable	
Intellectual Property Rights	
The contracting agency shall have unrestricted rights to all delivered reports and data. The contracting agency expects to place reports and data in the public domain. This specification places no restrictions on the contractor's rights to resell data or derivative products as the contractor sees fit.	

Difficult ground

Areas of extreme local relief and (or) poor access are more difficult to survey because of (1) inability to maintain a near-constant aircraft height above ground, (2) occasional occultation of the GPS satellite constellation, and (3) difficulty in adequately distributing GPS base stations and ground control points. In such circumstances it may be advisable to relax these specifications.

GPS procedures

All GPS measurements shall be made with dual frequency L1-L2 receivers with carrier-phase correction. All GPS measurements shall be made during periods with PDOP ≤ 3.0 and with at least 6 satellites in common view of both a stationary reference receiver and the roving receiver.

Stationary reference receivers shall be located at existing National Geodetic Survey (NGS) marks or at new marks. In the case of an existing mark, its location shall be verified by processing one GPS session of at least two hours duration and comparing the computed position with the position published by NGS. Each new mark shall be located by tying to one or more NGS Continuously Operating Reference Stations (CORS) by static GPS methods. If the distance to the nearest CORS is less than 80 km, use at least 2 independent GPS sessions, each at least 2 hours long. If the distance to the nearest CORS is greater than 80 km, use at least 2 sessions each at least 4 hours long.

At least two GPS reference receivers shall be in operation during all lidar missions, sampling positions at ≥ 1 Hz. The roving GPS receiver in the aircraft shall sample positions at ≥ 2 Hz. Differential GPS baseline lengths shall be no longer than 30 km.

Ground control points (GCPs), used for both survey calibration and assessment of absolute vertical accuracy, shall be established using GPS and (or) other techniques that are expected to result in accuracies of 1.5 cm (RMSE) or better. Strongly clustered GCPs are useful, perhaps even desirable, for calibration. Vertical accuracy shall be assessed by calculating and averaging the distances between a subset of at least 30 GCPs that are <u>not</u> clustered and a surface interpolated from lidar 1st returns. At least 20% of flight line swaths should contain points in this subset and the maximum distance between these GCPs should be no less than one-half the maximum distance across the survey area.

The *Report of Survey* shall document the identity, published position, and measured position of all existing NGS marks used for reference stations. The locations of new marks shall be described, along with their measured positions and the identity and published positions of CORS to which their locations were tied. The *Report of Survey* shall describe the technique(s) used to establish GCPs and document the positions and residuals of all GCPs used to evaluate survey accuracy.

Tiling scheme

A good tiling scheme has the following attributes: (1) tile boundaries can be computed readily, (2) adjacent tiles can be identified easily, (3) and tile names have meaning to the casual user. Tiles based on the Public Land Survey System meet attribute (3) but fail (1) miserably. Arbitrary tiling schemes (numbering from left to right and top to bottom, river miles, etc.) typically fail (1), often fail (2), and usually fail (3). Square tiles with boundaries at, for example, 1000 m intervals and named by northing and easting values of the SW corner meet (1) and (2) nicely, fail (3), and have the additional defect of being tied to a particular coordinate system—if the dataset is reprojected much of the utility of this naming scheme is lost. We thus specify a tiling scheme based on USGS 7.5-minute quadrangles, as tile boundaries can be computed without additional information, the names of adjacent tiles can be computed (though with difficulty), and tile names have some meaning.

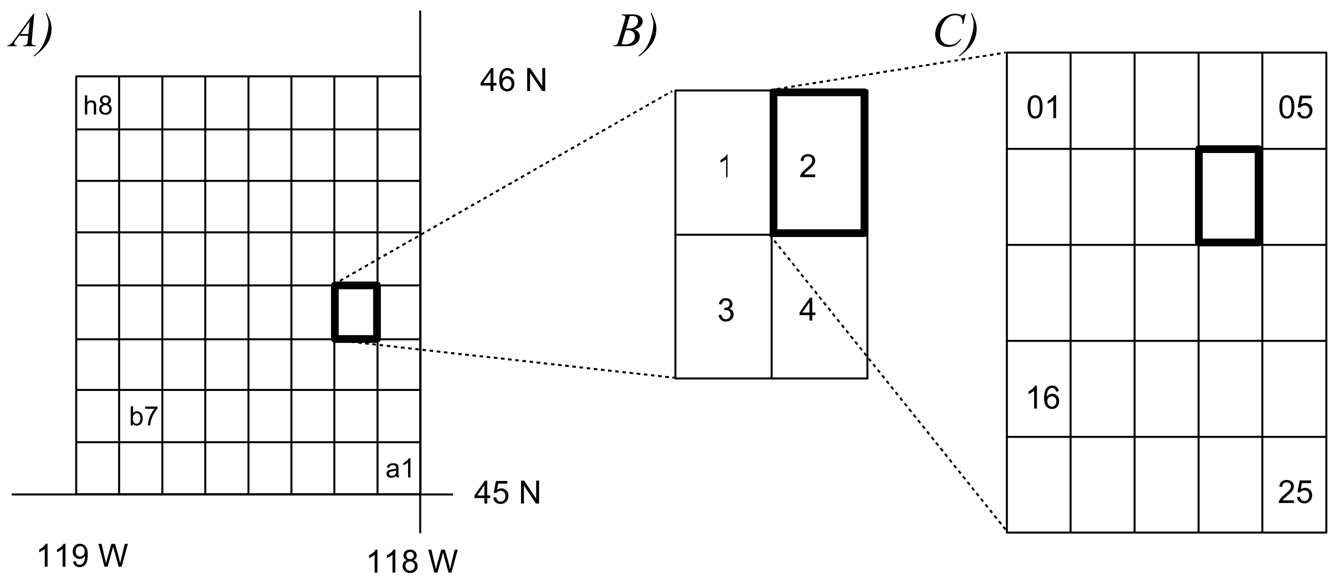
Data shall be delivered in tiles that are rectangular in geographic coordinates, correspond to standard USGS 7.5-minute quadrangles and divisions thereof, and are named according to the scheme

qAAOOORCQ (quarter-quadrangle, 3.75 minute by 3.75 minute region)
qAAOOORCQNN (1/100th quadrangle, 0.75 minute by 0.75 minute region)

where AA is the integer north latitude of the SE corner of the 1° x 1° region that contains the quadrangle,
OOO is the integer west longitude of the SE corner of the 1° x 1° region, R is the row, labeled from **a** to **h**, south to north, and C is the column, labeled from **1** to **8**, east to west. That is, in diagram A below of the 1° x 1° region with a southeast corner at latitude 45N, longitude 118W, the highlighted quadrangle is q45118d2.

Q is the quadrangle quadrant, which shall be numbered west-to-east, north-to-south, as is shown in diagram B below. That is, the highlighted quarter-quadrangle tile in diagram B is q45118d22.

QNN identifies the 1/100th quadrangle, which shall be labeled by numbering the 25 divisions of each quarter-quadrangle west-to-east, north-to-south, as shown in diagram C below. That is, the highlighted tile in diagram C is q45118d2209.



Return classification

We are unaware of any method for cheaply and accurately quantifying the accuracy of lidar return classification. In the absence of such a method, we specify that "Classification of returns shall be as complete as is feasible and without avoidable misclassification." We recognize that this specification is weak and look forward to discovery of a method for routinely quantifying the accuracy of return classification.

Definition of "feasible" and "avoidable" may require dialog between contractor and contracting agency. Dialog may also be necessary to establish the appropriate trade-off between automatic identification of most vegetation returns and failure to identify ground returns at landscape corners.

Returns from burn piles, stumps, downed logs, and almost all buildings shall be classified as vegetation, structure, not-ground, or left unclassified. Returns from highway embankments, retaining walls, bridge abutments, earthen berms, boulders, and plow ridges and furrows shall be classified as ground or left unclassified. Automatic return classification procedures tend to identify bridges and overpasses as not-ground and this is encouraged, for the resulting ground models will be more correct hydrologically.

Return classification procedures shall be documented in the *Report of Survey* and in formal metadata insofar as is possible without revealing trade secrets. Classification codes shall be defined in the *Report of Survey* and in formal metadata, with careful attention to the distinction between not-ground and unclassified.

Instructions on formal metadata

GIS-compatible data and files shall be explained with XML format metadata that follows the Federal Geographic Data Committee's (FGDC) Content Standard for Digital Geospatial Data. Metadata may be a single file that describes an entire survey or multiple files each of which describes a constituent part (e.g., area A, area B, area C) of the survey. Metadata shall include, but are not limited to, the following:

Color key: *To be completed by agency*
To be completed by contractor

Under *Identification* Information

Description, Abstract

An abstract summarizing the datasets delivered. Include project area. Include general tiling scheme (e.g., USGS 7.5 quarter quad). For each data layer, describe

Data structure and attributes, including resolution and precision

Total number of files

Time Period

Date(s) of data capture (range of dates)

For these dates, use the Current Reference: ground condition.

Status

Statement regarding completeness Status.

Spatial Domain, Bounding Coordinates and G-Polygon

Project survey area bounding coordinates in decimal degrees

Data Set Credit

Title for the name and address of the contractor who captured the data

Originator for the names of the agencies who contributed funds and participated in the acquisition of the data.

Other Citation Details for explanation of the acquisition: Agencies who participated in the contract (e.g., Kitsap County Department of Emergency Management administered the contract; Puget Sound Lidar Consortium served as technical resource and provided quality assessment, Oregon Department of Geology and Mineral Industries coordinated the participator requests; and agencies identified under Originator participated.)

Under *Data Quality*

Process Step

Process Description for manufacturer, model, and serial number of lidar instrument(s). May include separate specifications for scanning laser rangefinder, inertial navigation system, and GPS unit

Value(s) of instrument parameters during survey, including

- Nominal on-ground beam diameter
- pulse rate
- maximum number of returns recorded
- minimum separation between detected returns from a single pulse, expressed as a distance
- laser output power
- minimum return power required to produce a return
- beam wavelength
- frequency of GPS sampling
- frequency of IMU sampling

Nominal swath width

Nominal height of instrument above ground

Nominal single-swath pulse density

Nominal aggregate pulse density

Identity and assumed coordinates of reference survey monument(s)

Nature of vertical control (e.g., RTK GPS or water surface + tidal observations)

Calibration procedures

Return classification procedures

Positional Accuracy

Vertical Accuracy Report. Accuracy may be specified as RMSE or 95% confidence (indicate which). Vertical accuracy shall be reported for lidar measurements and, optionally, for the derived ground (bare-earth) surface model. XY accuracy of lidar measurements may also be reported. Shall include one or more of the following sections:

Accuracy as predicted by creator of survey

Accuracy as measured by creator of survey

Accuracy as verified by contracting agency or independent 3rd party

Under *Spatial Data Organization Information*

Indirect Spatial Reference

tiling scheme (if any). (e.g. ASCII data is divided into 1/100th USGS 7.5" quad)

Under *Spatial Reference Information*

Horizontal Coordinate System Definition:

Geographic Coordinate System for the captured data

Projected Coordinate System for the delivered data

Horizontal Datum for the delivered data

Ellipsoid Name (identify both the ellipsoid and the geoid model used to translate from ellipsoid to orthometric heights)

Vertical Coordinate System Definition

Datum Name

Vertical units

Under *Entity and Attribute Information*

Overview Description, Entity and Attribute Overview

Attribute descriptions if applicable (e.g. return point attributes in ASCII data or user bit field in LAS format). For all-return data, definition of return classification codes. Whether time is specified as GPS week and GPS second or Posix time. Any other relevant attribute information.

Under *Distribution Information*

Distributor

Distribution point of contact

Standard Order Process

Ordering Instructions - web location, if applicable

Fees – "There are no fees. This product is in the public domain."

Distribution Liability

Absence of intellectual property restrictions

Under *Metadata Reference Information*

Metadata Contact

Details for author(s) of metadata

Metadata Standard Name

"FGDC Content Standards for Digital Geospatial Metadata"

Metadata Standard Version

"FGDC-STD-001-1998" unless updated or otherwise substituted

File names

Names of data files shall be composed of the tile name followed, in some cases, by a suffix that denotes the data layer and (or) the file format. In some cases this name shall have additional suffixes that denote an export file and (or) file compression.

For the quarter-quadrangle q45123a3 and constituent 1/100th-quadrangle tile q45123a301, these are the names of data files:

all-return point cloud

q45123a301.las	(LAS file)
q45123a301.txt	(ASCII file)
q45123a301.txt.gz	(gzip compressed ASCII file)
q45123a301.txt.zip	(zip compressed ASCII file)

ground (bare-earth) surface model

q45123a3be	(ESRI grid name)
q45123a3be.e00	(ESRI export file)
q45123a3be.e00.gz	(gzip compressed ESRI export file)
q45123a3be.e00.zip	(zip compressed ESRI export file)

first-return (highest-hit) surface model

q45123a3hh	(ESRI grid name)
q45123a3hh.e00	(ESRI export file)
q45123a3hh.e00.gz	(gzip compressed ESRI export file)
q45123a3hh.e00.zip	(zip compressed ESRI export file)

ground point list

q45123a3.txt	(ASCII)
q45123a3.txt.gz	(gzip compressed ASCII file)
q45123a3.txt.zip	(zip compressed ASCII file)

first-return (highest-hit) intensity image

q45123a3hh.tif	(TIFF image; with accompanying .tfw file)

ground (bare-earth) contours

q45123a3.dxf	(CAD .dxf file)

q45123a3.dxf.gz	(gzip compressed .dxf file)
q45123a3.dxf.zip	(zip compressed .dxf file)
q45123a3.shp	(ESRI shapefile; with accompanying .dbf, .shx files)
q45123a3.shp.zip	(zip compressed ESRI shapefile: includes .shp, .shx, .dbf files)