



**AIRBORNE LASER SCANNING (ALS) OF AN AREA OF SPECIAL  
ARCHAEOLOGICAL INTEREST IN SOUTH-EASTERN BOSNIA AND  
HERZEGOVINA**

**'TECHNICAL SPECIFICATIONS'**

NUMBER: UPR-2024-ZN-0876

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## Abbreviations

ALS	Airborne Laser Scanning
ANGPD	aggregate nominal ground point density is the overall ground point density resulting from classifying the data from multiple passes of the lidar instrument, or a single pass of a platform with multiple lidar instruments, over the same target area
ATL1.0	ASPRS positional accuracy standards for digital geospatial data ver. 1.0
DEM	digital elevation model (an overreaching term for DTM, DFM...)
DFM	Digital Feature Model
DTM	Digital Terrain Model
GCPC	georeferenced and classified point cloud
GNSS	Global Navigation Satellite System
INS	Inertial Navigation System
KMZ	compressed Keyhole Markup Language format
LAS1.4	LAS Specification 1.4
NPD	nominal pulse density is average number of pulses within a specified areal unit. NPD is typically expressed as pulses per square meter.
OLS21A	USGS LiDAR Base Specification 2021 rev. A
overlap points	points in the overlap area of two or more flightlines
shp	ESRI Shapefile vector format
withheld points	points that may not be included in the data processing but remain in the original LAS data

## 1. INTRODUCTION

This document, hereafter referred to as the Technical Documentation, defines the scope and content of the performance of the procurement of the airborne laser scanning (ALS) of a specific area of archaeological interest in south-eastern Bosnia and Herzegovina. The foremost need of ALS data is for archaeological interpretation. The document describes the technical parameters of the data capture and processing, the content and scope of the deliverables, and the quality requirements of the deliverables to which the project deliverables must conform. The contractor shall fully comply with the technical documentation, which forms part of the contract between the Research Centre of the Slovenian Academy of Sciences and Arts and the tenderer selected in the call for tenders (the Contractor).

In addition to this document, which is the basic technical document with primary validity, the following documents, listed in order of priority, to which the technical document refers in part, should be considered in the event of any ambiguity:

- Lidar Base Specification ([LBS 2024 rev. A](#)), revised 25. January 2025 [1],
- LAS Specification 1.4 – R15 ([LAS1.4](#)), revised 9. July 2019 [2],
- ASPRS Positional Accuracy Standards for Digital Geospatial Data, ver. 1.0 ([ATL1.0](#)), revised November 2014 [3].

The main products of the project to be handed over are:

- a georeferenced and classified point cloud (GCPC),
- a digital terrain model (DTM), and
- a digital feature model (DFM).

A more detailed definition of the products is described in chapter 6.

In addition to the products handed over by the Contractor to ZRC SAZU, the Contractor shall keep the original full waveform ALS data for 3 years after the end of the contract. The original ALS data may be released in part or in full at the request of ZRC SAZU.

In addition to the deliverables, the Contractor shall also hand over to ZRC SAZU the metadata, a technical report and the other records specified in the technical documentation. The Contractor shall also hand over its internal reports in so far as they show that the control of intermediate and final products has been carried out and help ZRC SAZU to understand and control the execution procedures and the quality of the results. The Contractor's equipment must be calibrated by the manufacturer of the equipment. A certificate of calibration, no more than two years old, must be included with the tender.

The cost estimate should include all the necessary logistics, including aircraft, ground base stations, acquisition of ground control points, flight permissions, accommodation, etc.

Preparation and proposition for flight planning must be discussed with the project coordinator.

## 2. PROJECT AREA AND TIMING OF IMPLEMENTATION

The project area includes two zones in south-eastern Bosnia and Herzegovina. The region is karstic, with karst poljes separated by higher mountains and plateaus. Vegetation is mostly dense forest, woodlands and scrub with some meadows and fields.

### Scanning areas

For the location of the scanning areas see Figure 1 and attached vector files (shp and kmz). The location and shape of the areas have been selected in such a way as to facilitate straightforward data acquisition. The minimum requirement is to scan the smaller scanning area (blue, 1150 km<sup>2</sup>), while the desired extent is the red area that includes the blue one (3800 km<sup>2</sup>). They are limited to the east by the border between Bosnia and Herzegovina and Montenegro.

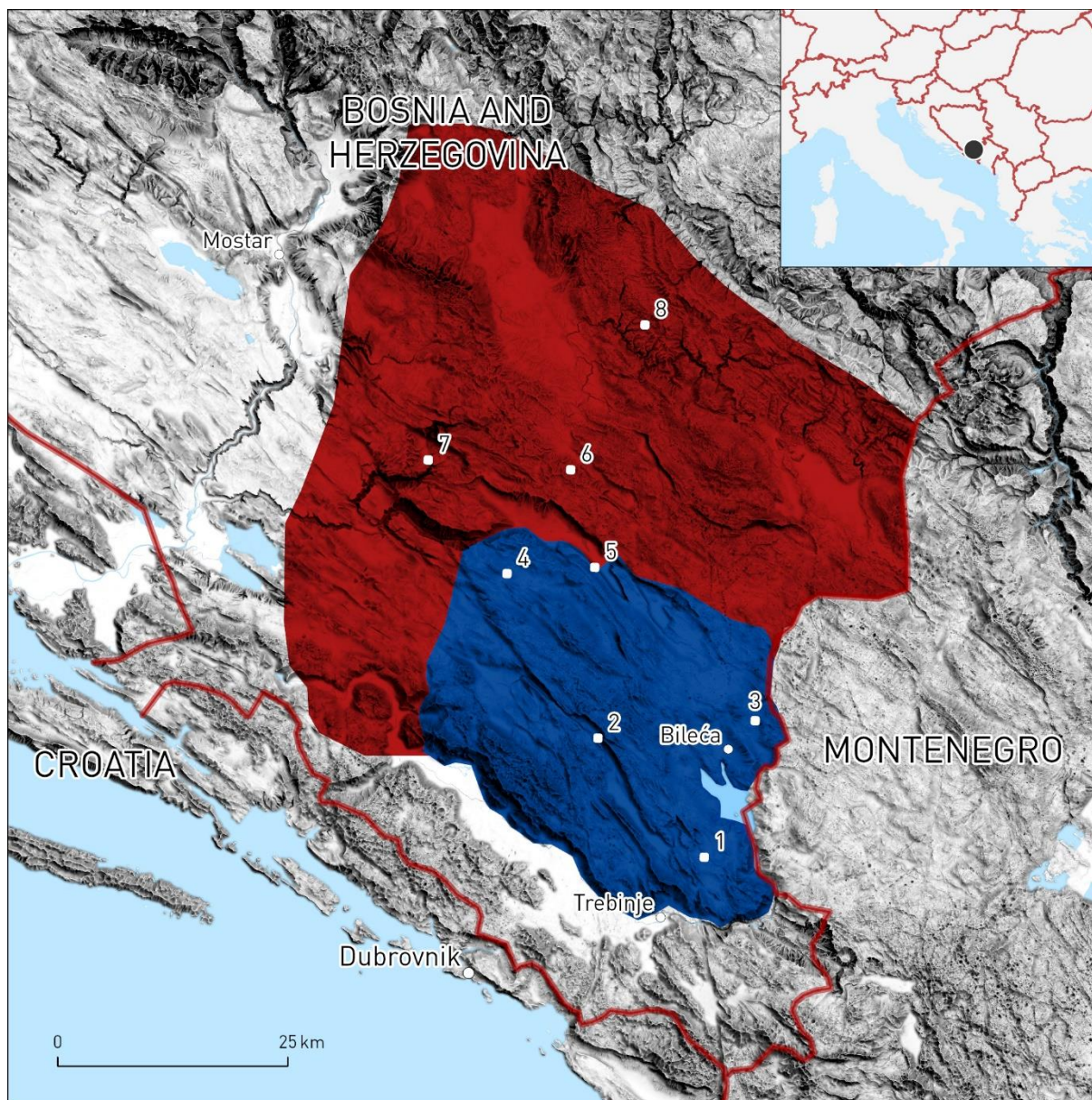


Figure 1: Location of the scanning areas. The blue area is the minimum requirement and the red area, which includes the blue area, is the desired extent. The white squares are sample areas. The regions in vector format (SHP and KMZ) are part of the Technical Documentation.

### Timeline for data capture and delivery of results

It is critical that data is acquired during the leaf-off period, therefore the preferred temporal window for ALS data acquisition is in early March 2025. The data acquisition must be finalized by 15 March 2025. The georeferenced and classified point cloud for the sample areas shall be submitted by the



contractor by 15 April 2025. The sample areas for the blue area must be submitted, but for the red area only if the contractor offers to scan it. All deliverables should be provided to ZRC SAZU no later than 30 June 2025.

### **3. DATA ACQUISITION REQUIREMENTS**

#### **Basic requirements**

The Contractor shall use the same laser scanning system specified in the proposal for data acquisition. The use of a different system shall be subject to the prior written approval ZRC SAZU. Prior to the data acquisition, the Contractor shall provide ZRC SAZU with a data acquisition plan containing the following information:

- a sketch in a shp format of all the planned ALS flightlines,
- technical specifications of the instruments to be used (laser scanner, GNSS, INS, etc.),
- the characteristics of the aircraft and planned flight(s) (manufacturer and type, minimum and maximum altitude, speed, etc.), and
- other parameters of the data acquisition (laser scanner acquisition angle, beam divergence, variations in the size of the laser beam footprint on the ground, scanning frequency, scanning pattern, overlap, etc.).

ZRC SAZU may make suggestions for improving the data acquisition plan. The Contractor may only start data acquisition after the implementation plan has been approved by ZRC SAZU, who will reply no later than 5 working days after receiving the data acquisition plan.

#### **Technical content of the offer for data acquisition**

The offer must be accompanied by a description of the implementation of the project on a maximum of 10 pages (A4) including:

- prepared flight plans with data in a digital format (i.e. in a shp format with appropriate attributes),
- a description of the procedures for data acquisition, performing calibrations and producing final deliverables, as well as the software packages used,
- a description of the quality control of final products and the provision of technical capacities for implementation,
- description of the most critical phases that could threaten the implementation of the project and mitigation measures.

The submitted descriptions and information related to the implementation of the project must meet the requirements as defined in the tender documentation. At the same time, by submitting the described procedures and information, the Contractor ensures the implementation of the project in accordance with the indications within its offer.

#### **Coordinate system**

Bosnia and Herzegovina is in the process of changing its national plan coordinate system Gauss-Kruger MGI 1901 (EPSG 31276) with elevations in the vertical reference system VRS1875 - NVT1 to the new national plan coordinate system BH\_ETRS89/TM with elevations in the vertical reference system BH\_VRS2020. The coordinate system information is published in the Rulebook on basic surveying work [4]. There are two issues that are important for a successful implementation of this project and have to be considered:

- A detailed geoid model for Bosnia and Herzegovina is not yet defined, therefore the height transformation has not yet been resolved.
- The new plan coordinate system and vertical reference system have not yet taken root in practice and practically all geospatial data in Bosnia and Herzegovina are still in the old systems. Data migration from the old to the new system will take at least another decade. The biggest problem is precisely the height transformation because the geoid is not defined. New levelling and gravimetric measurements were performed only for the Federation, and in Republic of Srpska they have not yet started with the measurements.

Therefore, all results should be delivered in the “old” national plan coordinate system Gauss-Kruger MGI 1901 with elevations in the vertical reference system VRS1875 - NVT1. If the height transformations become available, all data should be delivered also in the “new” systems.

## **4. QUALITY ASSURANCE**

### **Minimum requirements**

The quality level of the ALS data acquisition is defined by the following parameters:

- the required aggregate nominal ground point density (ANGPD) is  $\geq 8$  pts/m<sup>2</sup>, the higher ANGPD is  $\geq 12$  pts/m<sup>2</sup>,
- the required nominal pulse density (NPD) is  $\geq 15$  ps/m<sup>2</sup>, the higher NPD is  $\geq 25$  ps/m<sup>2</sup>,
- the maximum scan angle shall be 24° from nadir,
- the size of the laser beam footprint on the ground shall not exceed 30 cm (1/e<sup>2</sup>),
- maximum height deviation on flat surfaces within each flightline shall be  $\leq 0.04$  m,
- maximum height deviation on flat surfaces between overlapping flightlines shall be  $\leq 0.06$  m (OLS21A, Table 2, “Swath overlap difference”),
- the absolute planar accuracy of points on a well-defined detail along each axis shall be  $\leq 0.15$  m,
- the absolute planar accuracy of points on a well-defined detail shall be  $\leq 0.21$  m and with 95 % confidence of  $\leq 0.37$  m,
- the absolute height accuracy of points on bare surfaces shall be  $\leq 0.10$  m, and  $\leq 0.20$  m with 95 % confidence,
- the absolute height accuracy of points on vegetated surfaces shall be  $\leq 0.15$  m, and  $\leq 0.30$  m with 95 % confidence,
- ground classification algorithms must consider archaeological sensitivities,
- the resolution of digital elevation models (DTM, DFM) shall be 0.5 m.

All the calculated parameters and quality control findings should be reported in the metadata.

### **Instruments**

The Contractor shall use a full-waveform linear laser scanner with a wavelength of 1064 nm, capable of registering at least 4 simultaneous returns and of taking measurements from a minimum distance of at least 2500 m, with an accuracy of 25 mm or better. To be effective, the laser scanning system shall have a capacity to take at least 1,000,000 measurements per second. The instrument should be calibrated with a certificate not more than two years old issued by the equipment manufacturer. The calibration certificate should be submitted with the offer for data acquisition.

The laser scanning system shall be linked to high quality GNSS and INS to register the location as accurately as possible during acquisition, allowing sufficiently accurate georeferencing of the captured data.

The GNSS/INS system shall have the following characteristics:

- the frequency of operation of the INS unit shall be at least 256 Hz,
- heading accuracy  $\leq 0.01$  degrees Kappa,
- Roll/Pitch accuracy (Phi/Omega)  $\leq 0.005$  degrees,
- GNSS reading frequency of at least 2 Hz.

### **GNSS time**

The ALS data should be captured with a sufficiently high temporal resolution (GNSS time) so that each captured point has a unique time recorded.

### **Intensity values**

Each return point should have an intensity value recorded. The intensity value shall be normalised to 16-bit as specified in the LAS1.4 specifications. The normalisation of intensities shall be strictly linear. Other normalisation methods and value cut-off as minimum-maximum, standard deviation, percent cut-off, etc. are prohibited.

## Point density

Because the primary use of the acquired data is archaeological interpretation, ZRC SAZU are foremost interested in the accurate representation of terrain and small-scale morphological variations on it, also under the forest canopy. Therefore, the main parameter to be achieved is the *aggregate nominal ground point density* (ANGPD), which should be  $\geq 8$  pts/m<sup>2</sup>. Additional requirements are:

- 95 % of 25 m<sup>2</sup> squares shall contain at least 200 ground points,
- a further 4 % of the 25 m<sup>2</sup> squares shall have at least 100 ground points; and
- the remaining 1 % of the 25 m<sup>2</sup> squares shall have at least 50 ground points.

If the Contractor offers higher density scanning, the ANGPD to be achieved is  $\geq 12$  pts/m<sup>2</sup>. Additional requirements for higher density scanning are:

- 95 % of 25 m<sup>2</sup> squares shall contain at least 300 ground points,
- a further 4 % of the 25 m<sup>2</sup> squares shall have at least 150 ground points; and
- the remaining 1 % of the 25 m<sup>2</sup> squares shall have at least 75 ground points.

Only the non-withheld ground points shall be assessed. The actual ANGPD achieved shall be displayed in a graphical form (ANGPD GeoTIFF) and recorded in metadata.

The scanning areas of individual flightlines should have no data voids. A data void is defined as an area equal to or greater than 4 m<sup>2</sup> in which there is no ground point. Data voids are allowed for individual flightlines in the following exceptional cases:

- if they are located on water surfaces,
- if they are caused by low reflectivity of near-infrared light, such as by newly laid asphalt or by composite roofs,
- where there are no echoes due to obscuring from buildings or other objects,
- if they are on areas of anthropogenic objects where ground is not visible from the air (e.g. under buildings, bridges, viaducts).
- if they are covered by data from other flightlines.

Only the non-withheld ground points shall be assessed. Data voids shall be displayed in a graphical form (DV GeoTIFF with a 2 m pixel size) and recorded in metadata.

## Correctness of the spatial distribution

The distribution of ALS points shall be uniform and regular. The data acquisition must be designed and implemented in such a way that the merged ground points can be as close as possible to a uniform and correct grid. The uniformity of the grid and density of ground points across the scanning area will be assessed using the following methods:

- only the non-withheld ground points will be assessed,
- previously identified data voids will be addressed,
- a raster will be generated from the combined data with a pixel size of 0.5 m and indicating the number of ground points in each pixel (GPD GeoTIFF),
- it must be ensured that at least 95% of these cells contain at least 1 ground point.

If the Contractor offers higher density scanning, the GPD GeoTIFF should be generated with a pixel size of 0.33 m and it must be ensured that at least 90% of these cells contain at least 1 ground point. ZRC SAZU may, at the prior request of the Contractor, allow a reduction of these requirements in areas where a regular and uniform distribution of points is impractical.

## Duplicate points

Duplicate points (Easting, Northing, height, or time) are not allowed. All files with duplicate points will be rejected. Duplicate points with a spatial offset are also not allowed and will be rejected as duplicate points.

## Conditions for data acquisition

The basic time window for data collection is spring, when the trees are not yet in leaf. Data acquisition during the leaf-on period must be approved in writing in advance by ZRC SAZU.

The terrain must be free of snow cover. Data acquisition during snow cover must be approved in writing in advance by ZRC SAZU.

Data acquisition shall not be carried out during periods of high-water or even minor floods.



Atmospheric conditions between the aircraft and the ground should be cloud and fog free. Data acquisition shall not be carried out in adverse weather conditions such as high winds, rain, snow, fog, high humidity, and low cloud cover.

In the event of a long winter (snow accumulation well into spring) and/or prolonged bad weather in spring, data acquisition may be postponed to the autumn period; this may only be done with the written approval of ZRC SAZU by means of an addendum to the contract.

## 5. DATA PROCESSING

ALS point cloud should be without systematic errors and height differences between flight strips. Outliers shall be flagged.

### Tiling, file formats, naming convention, and file structure

The tiling follows the division per square kilometre ( $1000 \times 1000 \text{ m}^2$ ) for all products except the point cloud data, which should be delivered in smaller squares ( $500 \times 500 \text{ m}^2$ ). The boundary of the scanning area and the tiling division shall be recorded in a shp format. All products must be seamless at the boundaries, without gaps and without duplication.

The name of the point cloud files contains first the name of the scanning area and then the coordinates of the bottom left corner as shown in the example below:

- STONE\_eee\_nnn.laz – "eee" means Easting and "nnn" means Northing,
- the use of a leading zero is mandatory for Easting and Northing, e.g.  
STONE\_268500\_023000.laz.

The name of the gridded raster files contains first the name of the scanning area and then the coordinates of the bottom left corner, followed by the name of the product (e.g. DTM, DFM, ANGPD, GPD, DV) and the raster resolution (e.g. 05m, 2m, 5m) as shown in the example below:

- STONE\_eee\_nnn\_DFM\_05m.tif

Individual products should be stored in separate folders within the parent folder, e.g. STONE\LAZ, STONE\DTM...

### Point source ID

At the time of data acquisition and prior to further processing, each flight strip should be assigned a unique File Source ID. Each point within a single flight strip shall be assigned a Point Source ID, which shall be identical to the Source File ID. The Point Source ID shall remain unchanged throughout the processing and delivery of the products.

### Classification

The classification of all points that are not marked as withheld should include the following categories from the ASPRS classification scheme:

- 1 – unclassified or points that cannot be classified into other classes,
- 2 – ground and points below a bridge or a viaduct,
- 3 – low vegetation (< 3 m),
- 4 – medium vegetation (3 – 10 m),
- 5 – high vegetation (> 10 m),
- 6 – building (roof and walls),
- 7 – low point,
- 17 – bridge or viaduct,
- 18 – high noise.

All points belonging to the classification scheme and not marked as withheld shall be correctly classified. The classification of points must be consistent and uniform throughout the project. Noticeable differences in the method of classification, texture or quality of classification between different areas, flightlines, or other unnatural divisions will be grounds for rejection of the entire project. There shall be no Class 0 points within the final classified point cloud. A maximum of 0.5 % of the total points may be classified in Class 1 and a maximum of 0.05% of the total points may be classified in Class 7. There must be no points in Class 2 that could be assigned to other classes.

Ground classification accuracy will be checked against our ground measurements and with visual quality control.

### **Standard flags**

Points that cannot be reasonably interpreted as return points from a surface shall be given the withheld flag (as defined in LAS1.4). Examples of such points include erroneous points, geometrically unreliable points (noise), aerosol echoes, multiple reflections, returns from objects in the air or under the ground, points produced by sensor anomalies. The withheld flag may also be used in combination with specific classes (e.g. for low/high noise points), but must be used in all the above cases. The key point flag (as defined in LAS1.4) shall be used for model key points, if computed. The overlap flag (as defined in LAS1.4) shall be used for points in overlapping flightlines. They should be classified with the same process as non-overlapping points.

## **6. DELIVERABLES**

Point cloud files shall be in the LAS v. 1.4 – R15 format. The gridded raster files shall be in a GeoTIFF format, lossless compressed with LZW.

### **Georeferenced and classified lidar point cloud (GCPC)**

The point cloud should be corrected for positional errors and should include information on at least the following: X, Y, Z, intensity, scanning angle, time stamp, return number, number of returns, classification, echo width, strip ID, source ID (for scanning with multispectral systems).

### **Bare earth Digital Terrain Model (DTM)**

The bare earth terrain model is gridded at 0.5 m resolution from all non-withheld points with a class 2. Data format is compressed (LZW) GeoTIFF, units are meters.

### **Digital Feature Model (DFM)**

The digital feature model is gridded at 0.5 m resolution from all non-withheld points with classes 2 and 6. Data format is compressed (LZW) GeoTIFF, units are meters.

### **Metadata and technical report**

A technical report shall be provided for all processes and products, describing the performance of data acquisition and all stages of data processing. The report shall demonstrate that the results achieved meet the minimum requirements of the Technical Documentation.

The technical report shall contain the following information:

- a description of data acquisition and processing, and the production of deliverables,
- a description of any anomalies encountered during data acquisition such as:
  - adverse environmental conditions (e.g. heavy smoke, snow cover, flooded areas, leaf-on vegetation),
  - data capture problems (e.g. sensor problems, GNSS signal interruptions),
- records of the internal controls performed, the quality of the different data processing stages and the final products,
- information on how data voids, if any, were treated,
- information on all software packages used in the data validation and processing, their versions, methods, and processing parameters.

The technical report shall be in a MS Word and PDF formats.

The report shall be accompanied by a flight plan and boundaries of flight strips in a shp format, showing the realistic extent of all data captured.

Raster files in GeoTIFF format showing how the requirements have been met shall be submitted:

- the aggregate nominal ground point density (ANGPD) with 5 m pixel size,
- the nominal pulse density (NPD) achieved for each flightline with 5 m pixel size,
- the data voids (DV) with 2 m pixel size,
- the number of ground points in each pixel (GPD) with 0.5 m pixel size,
- the height deviation of ground points between overlapping flightlines with 1 m pixel size.

A sketch showing the quality assurance of the classification performed shall be submitted for the GCPC.

For DTM and DFM, the absolute height accuracy shall be calculated using the control points and the result displayed in MS Excel format.

## **7. WARRANTY**

If any of the requirements are not being met (data voids, aggregate nominal ground point density, nominal pulse density...), a new acquisition should be carried out by the data provider with all costs being borne by the data provider.

## **8. DATA OWNERSHIP AND SHARING TERMS**

ZRC SAZU reserves the right to freely build upon, enhance, reuse, share and license all the deliverables and other information resulting from this survey for any purposes without restriction.

## **9. BIBLIOGRAPHY**

1. U.S. Geological Survey Lidar Base Specification, 2024 Rev. A. **2024**, 46.
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4. *Pravilnik o Osnovnim Geodetskim Radovima*; Federal administration for geodetic and property affairs: Sarajevo, 2019; p. 34;.