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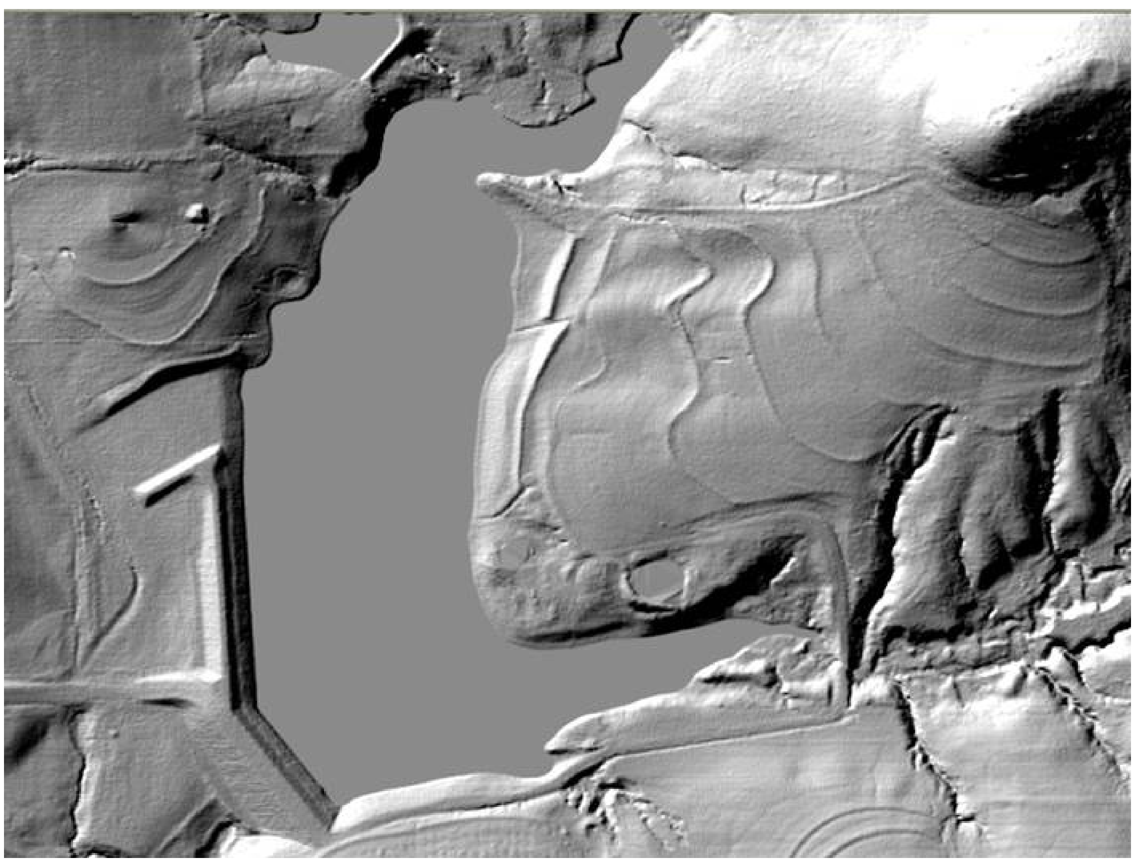
Using LiDAR for Planning and Designing Engineering Practices



Cover photo: PL–566 structure, Marthasville Watershed, site MV–5, Warren County, MO

Acknowledgments

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Using LiDAR for Planning and Designing Engineering Practices

Scope

This technical note provides information and recommendations for the use of light detection and ranging (LiDAR) for planning and designing engineering practices. Although this technical note makes reference to different types of LiDAR data, it is primarily geared toward aerial-based LiDAR.

Background information

LiDAR is a laser-based remote sensing technique used for measuring distances by illuminating targets with a single laser pulse and analyzing the timing of the reflected light, which can be used to generate elevation data. Coupling the laser with a global positioning system (GPS) provides locational information.

LiDAR data can be acquired by several methods. The most common to Natural Resources Conservation Service (NRCS) are aerial-based systems, which are used to collect data over large areas. Other methods of acquiring LiDAR data include terrestrial and mobile, using a vehicle or unmanned aerial vehicle (UAV). These ground-based and mobile systems are less common to NRCS, and are typically used to provide high-quality high-definition data over a smaller, typically site-specific, areas.

LiDAR data consists of elevation points of the ground surface and any other surfaces that reflect the light source. This would include buildings and vegetation, but usually not anything below water. Special equipment is needed to obtain bathymetric readings below water levels. The data are post processed to contain only the bare earth surface, all of surfaces encountered, or a selected subset of the surfaces.

LiDAR suitability for conservation engineering work is determined by data quality, such as the accuracy and precision of the LiDAR dataset. Data quality is impacted by aerial flight precision, type and execution of elevational ground control, the rate and density of sampling, and the level of post processing. Other considerations include the format and projection of the data provided to the user, manipulation of the LiDAR by the user, site changes since LiDAR data collection, and the scope of engineering project.

LiDAR is available in many areas and in various degrees of quality. Table 1 provides specifications for five quality levels. Much of the airborne LiDAR currently available is quality level (QL) 3.

Table 1 Quality level (QL) specifications

Elevation [1/] quality level (QL)	Horizontal resolution terms		Vertical accuracy terms	
	Point density, points/m^2	Nominal pulse spacing, m	RMSEz [2/] in open terrain, cm	Equivalent contour accuracy, ft
QL 1	8	0.35	9.25	1[3/]
QL 2	2	0.7	9.25	1
QL 3	1–0.25	1–2	≤18.5	2
QL 4	0.04	5	46.3–139	5–15
QL 5	0.04	5	92.7–185	10–20

[1/]Quality levels are based on National Enhancement Elevation Assessment (NEEA) quality levels

[2/]RMSEz = Root mean square error in the vertical direction.

[3/]QL1 is needed to obtain accuracy for sites with heavy canopy or vegetative cover

Metadata and accuracy

When LiDAR is used, design documentation must include metadata relevant for the LiDAR form used to demonstrate that the data are adequate to support the intended use. The metadata may include, but are not limited to the following:

- Quality level (QL)
- Date of the flight or scans
- Flight elevation
- Point density
- Post processing method and precision
- Average point spacing
- Final root mean square error in the vertical direction (RMSEz)
- The type of geographic projection used in collection and post-processing
- Geographic projection units

LiDAR must meet fundamental vertical accuracy for the desired QL listed in table 1 at the 95-percent confidence level using RMSEz x 1.9600 as defined by the Federal Geographic Data Committee (FDGC) Geospatial Positioning Accuracy Standard, Part 3: National Standard for Spatial Data Accuracy (NSSDA). The supplemental NSSDA vertical accuracy value reflects the accuracy at the 95th percentile of tested points in land cover areas other than open terrain. Table 2 provides the comparison of the vertical accuracies.

Table 2 Comparison of vertical accuracies

Equivalent contour interval National Map Accuracy Standard (NMAS) (ft)	**RMSEz NSSDA (ft)**	**Accuracy$_{(z)}$ NSSDA (ft)**
0.5	0.15 (4.60 cm)	0.30 (9.10 cm)
1	0.30 (9.25 cm)	0.60 (18.2 cm)
2	0.61 (18.5 cm)	1.19 (36.3 cm)
4	1.22 (37.0 cm)	2.38 (72.6 cm)
5	1.52 (46.3 cm)	2.98 (90.8 cm)
10	3.04 (92.7 cm)	5.96 (181.6 cm)

Factors that may limit LiDAR suitability include vegetative cover and/or buildings at the time of data collection, changes at the site after data collection, site-specific features that may not have been collected (for airborne: culvert inlets and outlets, fences, wells, wooded areas, etc.), and the presence of surface water. Although LiDAR scans penetrate water surfaces, the resulting data is considered unreliable. Therefore, ground elevations below a water surface must be surveyed by another method. Consideration must be given to the changes made to the landform that have occurred after the LiDAR surface acquisition, particularly when used for hydrology purposes on relatively small sites. Construction of terraces, diversions, roadways, and general site development can alter watershed boundaries and flow paths. Using current aerial photography is one method to identify landform changes.

LiDAR data are collected as variable density point data occasionally referred to as a "point-cloud." These data are typically processed, displayed, and utilized as grid data. Depending on the density of the original point cloud and the derivation and size of the distilled grid information, some locations and elevations can be distorted or omitted all together. Often, a secondary processing must be done to ensure flow paths are properly linked and coincide with features such as culverts and bridges. Techniques referred to as "flow accumulation" and "contour vectors" help provide the locations of features such as ditch bottoms or other significant grade changes. The user must always be cognizant of the fact that features significantly smaller than the post processed grid size may either be missing or may have been created through secondary processing, and hence could be artifacts of the processing itself. For example, according to LiDAR Base Specification Version 1.0, the minimum QL 3 relative vertical accuracy within individual swaths is <= 7 cm RMSEz. According to this standard, a resulting grid will accurately capture the location of ditch bottoms and the subsequent flow path within the grid-raster cells. While the exact location of ditch bottoms is never precisely shown with the LiDAR flow accumulation raster, the flow path position is in fact represented with high relative detail for use in practical applications such as planning grassed waterway. For example, although the ditch bottom could actually exist one grid cell to either side of where it is shown, the slope of the channel depicted should be very close to the actual slope of the ditch.

Airborne LiDAR inventory

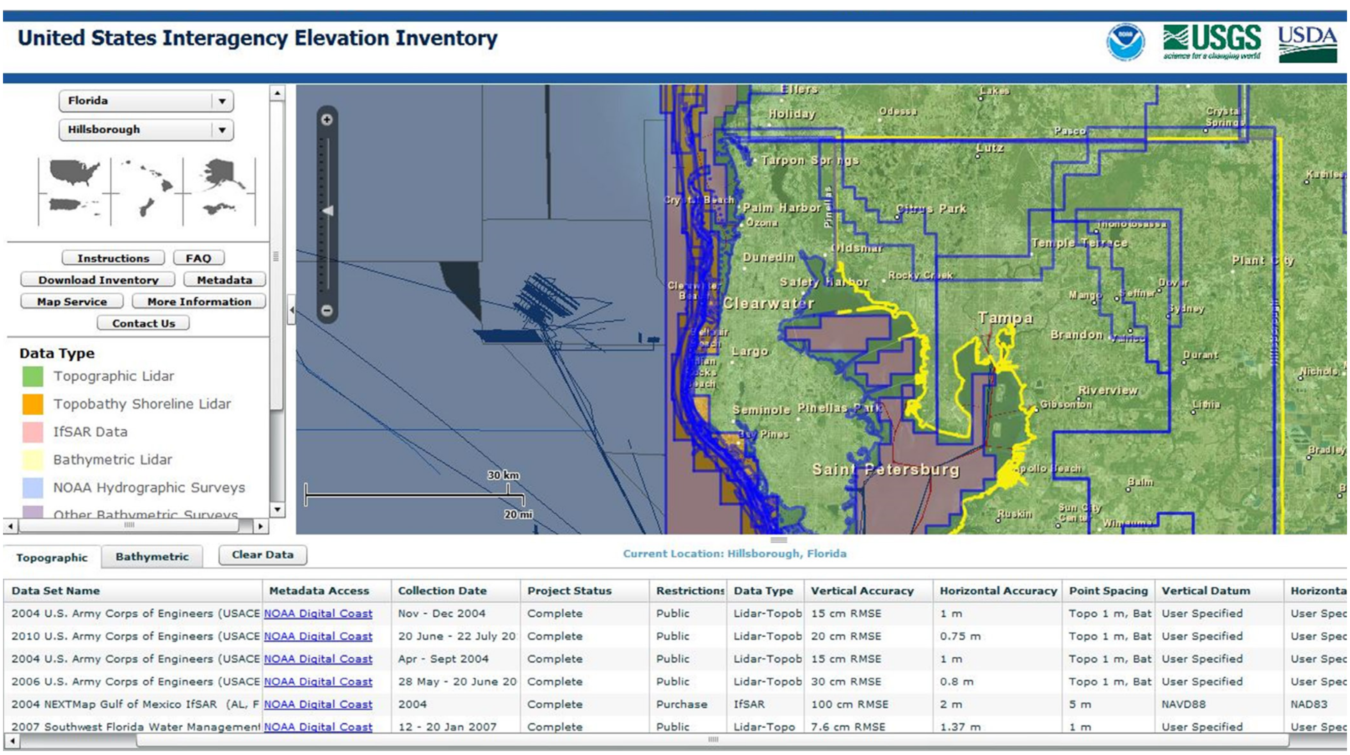
The National Oceanic and Atmospheric Administration (NOAA) provides a Web-based user interface (fig. 1) that allows the user to view available airborne LiDAR from various sources and can be queried by State and county. The vertical accuracy is included as an attribute in the summary table, allowing inference of the QL and supportable precision and contour interval as listed in table 1.

Other types of LIDAR may be available but tend to be limited to states that acquire it. At this time there is not a national repository for such LiDAR data sets. The Web address to the NOAA user interface web is *http://www.csc.noaa.gov/inventory/#*

NRCS stores 1- and 2-meter bare earth rasters in the USDA Geospatial Data Gateway (GDG) (fig. 2). When NRCS purchases LiDAR data, NRCS requests that the LiDAR provider create bare earth and any relevant surface models. These data are stored as digital elevation models, square grids with attributes assigned to each square, most usually the elevation. Data sets loaded on the Gateway have passed a quality review process to ensure that they meet specifications. There are currently 279 tiles for 1-meter rasters and 273 2-meter rasters available. Each tile is equivalent to a 7.5-minute quadrangle map, with a naming convention the same as the official USGS quadrangles. National Geospatial Center of Excellence (NGCE) is adding more quadrangles on a regular basis.

NRCS also has a partnership to serve USGS National Elevation Database (NED) rasters at 60-, 30-, 10-, and

Figure 1 NOAA's Web site of the U.S. Interagency Elevation Inventory



3-meter resolutions (fig. 2). The Gateway elevation services that have a white background in product catalog are available to the public. The Intermap Interferometric Synthetic Aperture Radar (IFSAR) data services have a grey background and are licensed only to USDA, NRCS and Farm Service Agency (FSA). The Web address to the USDA GDG is *http://datagateway.nrcs.usda.gov/*.

Use of LiDAR for engineering practices

LiDAR is generally well suited for engineering planning and LiDAR datasets that have been properly verified may be well suited for certain portions of final designs. The designer must evaluate the data to verify that the accuracy is appropriate for the proposed engineering works of improvement, such as hydrology, channel hydraulics, structural layout, stage-storage computations, earthwork quantity computations, etc. For design of engineering practices, table 3 presents examples of design uses and practice types with the corresponding minimum required LiDAR QL.

The user needs to consider how the different approaches (triangulated irregular network (TIN), digital elevation model (DEM), contours, data sampling, data thinning, etc.) affect the raw data. Depending on how the data is processed, LiDAR data that starts out as meeting the accuracy requirements for a particular design use might be turned into a product that no longer meets the necessary accuracy. For example, LiDAR data from a 3-meter DEM may not meet the accuracy requirements needed even though the same LiDAR data at a 1-meter DEM spacing would.

When employing LiDAR for the design uses shown in table 3, field verification (groundtruthing) of the data is required prior to final design, at a minimum. The process of field verification may include, but may not be limited to, the following steps:

Step 1: Establish temporary benchmarks and control points on site. These survey control points must be in the projection and datum used in the LiDAR coverage.

Step 2: Perform additional survey for at 20 locations outside of any areas of active erosion, obtaining elevations and position, using the site benchmarks. Check locations with significant vegetative cover as well as locations with bare ground, to determine if any inaccuracies due to vegetation exist in the LiDAR data. Take survey check points where the slope is uniform for a radius greater than the nominal grid spacing of the DEM. Where possible, establish at least one survey check point on hard infrastructure such as a concrete pad, bridge deck, or culvert headwall.

Step 3: Check to ensure that the LiDAR data accurately represents the site and that the actual project location has been correctly identified. If the elevations have the required precision and accuracy but have a consistent location or elevation shift or bias between the surveyed elevations and the LiDAR surface, it may be possible to apply an elevation adjustment. If the precision and accuracy is not acceptable and there is a discrepancy which cannot be reconciled, discontinue use of LiDAR for that site. For further guidance on precision and accuracy, refer to Engineering Field Handbook (EFH), 650.0102.

Step 4: Gather survey data as needed for any portions of the site that are under water (or were underwater at the time of LiDAR data collection), for grade breaks not fully modelled by LiDAR (flowlines and banks), and for any portions of the site that are actively eroding (gullies or headcuts). Use this site specific information to supplement or replace LiDAR data as appropriate for the design.

Step 5: Gather survey data at exposed geologic features, utilities, right-of-ways, and property boundaries.

Step 6: Set flags or other markings to lay out the proposed practice for construction and compare the layout elevations to the design LiDAR surface elevations to determine if difference observed are acceptable for the given practice.

Figure 2 USDA Geospatial Data Gateway

Bare earth rasters and hillshade data can be ordered by quad tiles where available. User picks resolution by choosing the products in the catalog.

LiDAR Elevation Dataset—Bare Earth DEM's

There is a status map for 1 and 2 meter datasets.

Elevation	LiDAR Elevation Dataset - Bare Earth DEM - 1 Meter		USDA	geoTIFF	AutoUTM to quadrangle
	LiDAR Elevation Dataset - Bare Earth DEM - 2 Meter		USDA	geoTIFF	AutoUTM to quadrangle
	National Elevation Dataset 3 Meter		USGS	geoTIFF	AutoUTM to quadrangle
	National Elevation Dataset 10 Meter		USGS	geoTIFF	AutoUTM to quadrangle
	National Elevation Dataset 30 meter		USGS	geoTIFF	AutoUTM to quadrangle
	National Elevation Dataset 60 meter (AK)		USGS	geoTIFF	AutoUTM to quadrangle
	IFSAR Elevation Digital Terrain Model (DTM)		INTERMAP	geoTIFF	AutoUTM to quadrangle
	IFSAR Elevation Digital Terrain Model AK (DTM)		USDA	geoTIFF	Albers
Elevation Derivatives	LiDAR Elevation Dataset - Bare Earth Hillshade - 1 Meter		USDA	geoTIFF	AutoUTM to quadrangle

Table 3 Examples of minimum LiDAR quality level recommended for practice design use and applicable practice types

Design use	Applicable practice types	Minimum quality level requirement
Stage storage computations	Wetland or water impoundment stage storage areas	QL 2
	Pond or dam reservoir impoundment stage storage areas	QL3
Excavation	Wetland macrotopography areas	QL 2
Waterway channel hydraulics	Grassed waterways, terraces, etc.	QL 2
Grade and location	Pipelines and irrigation systems	QL 3
Channel/floodplain cross sections	Flood routing/stage capacity	QL 2
Watershed hydrology: area, slope, and flow length determination	All types	QL 3