FAQ #23: How are inland and nearshore bathymetric and topobathymetric data produced and how are their Quality Levels (QLs) defined?

Bathymetric Mapping Technologies

For bathymetric mapping, airborne lidar bathymetry (ALB) is a technique for measuring the depths of moderately clear waters from a low-altitude aircraft using a green-wavelength scanning, pulsed laser beam. ALB have larger beam divergence and have greater depth penetration capability, up to 60 m water depths in clear water, and use sophisticated waveform analysis-based algorithms to determine water depth (Figure 61).

Topobathymetric lidar systems, also called topobathy systems, have smaller beam divergence with less penetration capability, up to 10 m water depths in clear water, and rely on a simple refraction correction technique to determine water depth. Most bathymetric and topobathymetric LiDAR systems can also provide topography data over land areas.

Acoustic Survey Systems (sonar) has long been used for bathymetric mapping and hydrographic surveying. Sonar systems use sound waves and echo sounders to measure water depths. Although there are several different types of sonar systems, multi-beam echo sounders (MBES), also called multibeam sonars, are generally best for broad area coverage, being similar to lidars in that they collect swaths of depth data with individual beams as shown in Figure 62.

Figure 61. Bathymetric and topobathymetric lidar, with green laser, map water surface and submerged topography.

Figure 62. Individual beams in a multibeam transducer form a swath of elevation (depth) points.
Bathymetric Lidar Advantages

Bathymetric or topobathymetric lidar (Airborne Lidar Bathymetry – ALB) measures the depths of moderately clear, near-shore coastal waters, lakes, and rivers from a low-altitude aircraft. The round-trip time-of-flight of each laser pulse to the water surface and sea floor is measured by receivers in the aircraft. With this information, and the speed of light in air and water, accurate water depth can be calculated. This technique is also known as airborne lidar hydrography (ALH) when used primarily for nautical charting.

This is important because hydrographic charts for many of the world’s coastal areas are either out of date or nonexistent. The overall status of hydrographic surveying and nautical charting world-wide is rated in the range from poor to fair (UN, 1989). Hydrography, worldwide, is in a state of crisis regarding the ability of professional hydrographic organizations to provide the needed and desired products within their budgets and in a timely manner. Bathymetric lidar can deliver faster and cheaper shallow-water surveying for both hydrographic and bathymetric purposes.

Bathymetric lidar has proven to be an accurate, cost-effective, rapid, safe, and flexible method for surveying in shallow water and on coastlines where sonar systems are less efficient and can even be dangerous to operate.

The costs of operations for all current ALB systems are reported most often as 15-30% of the standard acoustic survey cost, depending on location, depth, and survey density. ALB soundings are densely spaced, typically on a 0.5-5 meter grid, within a wide swath under the aircraft, whose width is roughly typically greater than half of the aircraft altitude. The major limitation is water clarity. For areas with very clear water, the advantage of surveying a wide swath at aircraft speeds can be obtained for depths as great as 50 meters or more. The fact that airborne lidar can also measure land topography and survey simultaneously on both sides of the land/water boundary is highly beneficial and attractive to coastal engineers. Figure 63 presents a graphic comparison of lidar and sonar operations in shallow water.

![Figure 63. Depiction of lidar and multi-beam sonar operation in shallow water to emphasize lidar capabilities and efficiency.](image)
Bathymetric Lidar Limitations

The major limitation of bathymetric or topobathymetric lidar is that success is largely dependent on the clarity of the water. Bathymetric or topobathymetric lidar cannot map the subsurface terrain beneath the muddy Mississippi River, lakes covered with algae, wetlands with murky waters, and shorelines with high sediment suspension from surf action. See Figures 64 and 65. The ability to determine the sea bottom is also dependent on the type of sensor being used. Traditional bathymetric lidar sensors that have a high-power wide beam are able to better penetrate through turbid waters. Topobathymetric sensors typically have lower power and utilize a narrow beam that results in more potential voids in turbid waters, but they are cheaper to operate. Bathymetric surveys must be conducted during periods of most optimal water clarity; sometimes water clarity changes seasonally or even daily.

Sonar Comparisons

Complete, high-resolution bathymetric surface models can, and have been for decades, developed using vertical beam echo sounder (VBES) techniques; however, the more modern multi-beam echo sounder (MBES) performs more quickly and efficiently in water depths deeper than about 20 meters. In calm waters shallower than ten meters, sweep sonar is very effective, and interferometric sonar sensors are effective at bathymetry between one and 20 meters deep. As object size decreases, side scan sonar may be used whenever object detection is the primary reason for surveying and environmental factors allow it to be accomplished safely. There is competition between the different sonar types with regard to which is best to use for a particular survey requirement, but they still represent the same basic acoustic technology. Figure 63, above, compares multi-beam sonar with ALB or topobathymetric lidar.

Bathymetric and Topobathymetric Quality Levels

The National Science and Technology Council has developed the National Coastal Mapping Strategy 1.0: Coastal LiDAR Elevation for a 3D Nation, in which it proposes bathymetric equivalents (QL0b, QL1b, QL2b, QL3b, and QL4b) to topographic data Quality Levels in the USGS Lidar Base Specification (QL0 HD, QL0, QL1 HD, QL1, QL2, and QL5).

User requirements for bathymetric and/or topobathymetric data will be defined at five potential bathymetric Quality Levels (Table 12) consistent with standards of the International Hydrographic Office (IHO), USACE hydrographic survey requirements, the IWG-OCM National Coastal Mapping Strategy, and Quality Levels being considered for the 3D Nation. Note that QL0b and QL1b are equivalent to the IHO Special Order standard for vertical accuracy, and the vertical accuracy specification for QL4b is equivalent to the IHO Order 1 standard for...
vertical accuracy. The higher-density QL0\(\_\text{B}\) and QL2\(\_\text{B}\) are better for detection of submerged objects that may be hazardous to marine navigation.

Table 12. Bathymetric/Topobathymetric Lidar Data Density and Absolute Vertical Accuracy

<table>
<thead>
<tr>
<th></th>
<th>QL0(_\text{B})</th>
<th>QL1(_\text{B})</th>
<th>QL2(_\text{B})</th>
<th>QL3(_\text{B})</th>
<th>QL4(_\text{B})</th>
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<tr>
<td>IHO Special Order</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate Nominal Pulse Spacing</td>
<td>≤0.7 m</td>
<td>≤2.0 m</td>
<td>≤0.7 m</td>
<td>≤2.0 m</td>
<td>≤5.0 m</td>
</tr>
<tr>
<td>Aggregate Nominal Pulse Density</td>
<td>≥2.0 pts/m(^2)</td>
<td>≥0.25 pts/m(^2)</td>
<td>≥2.0 pts/m(^2)</td>
<td>≥0.25 pts/m(^2)</td>
<td>≥0.04 pts/m(^2)</td>
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<tr>
<td>Depth Examples (m)</td>
<td>Vertical Accuracy of submerged elevations at 95% Confidence Level (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>25.0</td>
<td>25.0</td>
<td>30.0</td>
<td>30.0</td>
<td>50.0</td>
</tr>
<tr>
<td>10</td>
<td>26.1</td>
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<td>32.7</td>
<td>32.7</td>
<td>51.7</td>
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<tr>
<td>20</td>
<td>29.2</td>
<td>29.2</td>
<td>39.7</td>
<td>39.7</td>
<td>56.4</td>
</tr>
<tr>
<td>Applications</td>
<td>Detailed site surveys requiring the highest accuracy and highest resolution seafloor definition; dredging and inshore engineering surveys; high-resolution surveys of ports and harbors</td>
<td>Charting surveys; regional sediment management; general bathymetric mapping; coastal science and management applications; change analysis; deep water surveys; environmental analyses</td>
<td>Recon/planning; all general applications not requiring higher resolution and accuracy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Definitions of terms relevant to the terminology used in Table 12 are included below.

**Nominal Pulse Spacing (NPS)** — A common measure of the density of a point-based elevation dataset (e.g., lidar, IfSAR, sonar), it is the typical or average lateral distance between points in a dataset, most often expressed in meters. NPS refers to the average point spacing of a dataset typically acquired in a zig-zag pattern with variable point spacing along-track and cross-track. NPS is an estimate and not an exact calculation.

**Aggregate Nominal Pulse Spacing (ANPS)** — A variant of nominal pulse spacing (NPS) that expresses the typical or average lateral distance between pulses in a dataset resulting from multiple passes of the sensor, or a single pass of a platform with multiple sensors, over the same target area.

**Nominal Pulse Density (NPD)** — A common measure of the density of a single pass (single swath) of a point-based elevation dataset (e.g., lidar, IfSAR, sonar), expressed as points per square meter (PPSM), normally used when the Nominal Pulse Spacing (NPS) is less than one meter. PPSM = 1/NPS\(^2\).

**Aggregate Nominal Pulse Density (ANPD)** — A variant of nominal pulse density (NPD) that expresses the total expected or actual density of pulses occurring in a specified unit area resulting from multiple passes of the sensor, or a single pass of a platform with multiple sensors, over the same target area.
Bathymetric Vertical Accuracy — The value by which vertical accuracy of submerged topography mapped with topobathymetric or bathymetric sensors (e.g., lidar, sonar) can be equitably assessed and compared among datasets when applying the ASPRS Positional Accuracy Standard for Digital Geospatial Data. For practical purposes, absolute vertical accuracy of submerged topography can only be determined for nearshore bathymetry where GPS antenna on elevated range poles can be used to measure submerged QA/QC checkpoints. Then, the vertical accuracy at the 95% confidence level is determined by multiplying RMSEz x 1.9600.