# LIDAR and Digital Elevation Data

Light Detection and Ranging (LIDAR) is being used by the North Carolina Floodplain Mapping Program to generate digital elevation data. These highly accurate topographic data are then used with other digital information and field data to analyze flood hazards and delineate floodplain boundaries, which are depicted on Flood Insurance Rate Maps. This fact sheet provides information on this new technology and the resulting products being created and distributed. For more information on LIDAR technologies and digital elevation data, the best overall reference is *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, by the American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 2001.

How Does LIDAR Acquire Data?

Airborne LIDAR sensors emit between 5,000 and 50,000 laser pulses per second in a scanning array. The most common scanning arrays, as shown below, go back and forth sideways relative to the points measured on the ground. The scan angle and flying height determine the average point spacing in the cross-flight direction, whereas the flying height and the airspeed determine the average point spacing in the in-flight direction. Each laser pulse has a pulse width (typically between 0.5 and 1 meter in diameter) and a pulse length (equivalent to the short time lapse between the time the laser pulse was turned on and off). Therefore, each laser pulse is actually like a cylinder of light with diameter and length.

Several technologies operate for LIDAR to survey high-accuracy data points on the ground:

Airborne LIDAR System
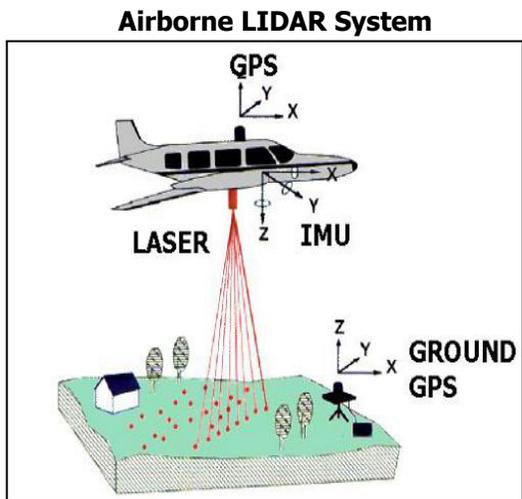
- Airborne Global Positioning System (GPS) is needed to determine the x, y, and z coordinates of the moving LIDAR sensor in the air, surveyed relative to one or more GPS base stations.
- The Inertial Measuring Unit (IMU) directly measures the roll, pitch, and heading of the aircraft, establishing the angular orientation of the LIDAR sensor about the x, y, and z axes in flight.
- The LIDAR sensor measures the scan angle of the laser pulses. Combined with the IMU data, this establishes the angular orientation of each laser pulse.
- The LIDAR sensor measures the time needed for each emitted pulse to reflect off the ground (or features thereon) and return to the sensor.

LIDAR sensors are capable of receiving multiple returns, some up to five returns per pulse. This means that a 30-KHz sensor (30,000 pulses per second) must be capable of recording up to 150,000 returns per second. The "first return" recorded by a LIDAR sensor is the first thing hit by a laser pulse. This could be a treetop, roof, ground point, or a bird in flight. When a laser pulse hits a soft target (e.g., a forest canopy), the first return represents the top of that feature. However, a portion of the laser light beam might continue downward below the soft target and hit a tree branch. This would provide a second return. Theoretically, the last return represents the bare earth terrain, but this is sometimes not the case. Some vegetation is so thick that no portion of the laser pulse penetrates to the ground. This is usually the case with sawgrass, mangrove, and dense forests where a person on the ground cannot see the sky through the canopy. LIDAR for the North Carolina Floodplain Mapping Program was flown during "leaf off" conditions to favor the acquisition of bare earth data.

How are the Data Acquired by LIDAR Refined?

The major cost for LIDAR in the North Carolina Floodplain Mapping Program is vegetation removal, which involves the post-processing of the data to generate bare earth digital information. To get these bare-earth elevation data, automated and manual post-processing are used to eliminate points that impinged on elevation features. This creates data voids, so that the dataset becomes more irregular with regard to point spacing on the ground. Automated post-processing includes computerized procedures that detect elevation changes that appear to be unnatural. For example, rooftops are identified with relative ease because there are abrupt elevation changes between the yard and the rooftop. However, vegetation provides more difficult challenges for automated procedures.

**Pre-Processed LIDAR Data in an Urban Area**
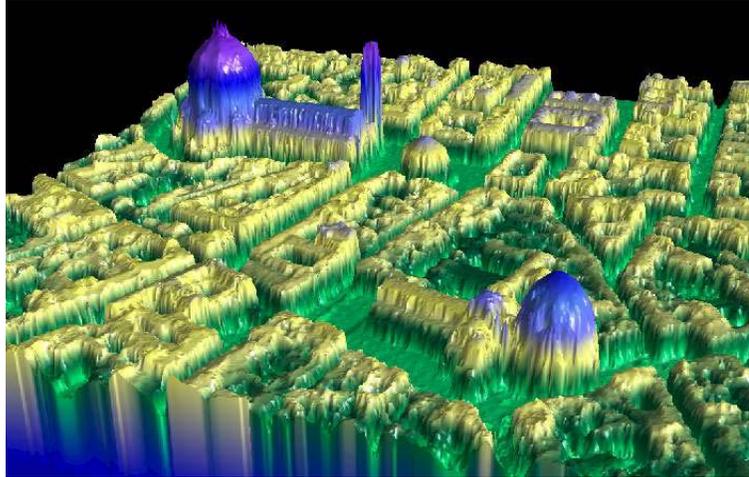
Manual post-processing is more accurate (and more costly) and normally includes the overlay of data points on digital imagery so the analyst can see where the laser points hit the ground. This can be problematic if the imagery was not flown concurrent with the LIDAR data and some features moved (e.g., vehicles along a road) or otherwise changed between the acquisition of LIDAR and the image. Furthermore, LIDAR is often flown at night, whereas imagery is photographed during daylight hours when the sun angle is suitable.

How are the Data Checked?

Field survey checkpoints are obtained to evaluate the accuracy of LIDAR products. A minimum of 100 checkpoints are tested in a county. At least 20 for 5 different land vegetation categories (forest, built-up, scrub, weeds/crop, and bare-earth/low grass) are tested with forested areas requiring a minimum of 40 checkpoints. A statistical analysis between the difference in elevations of the field survey checkpoints and LIDAR-derived, bare earth elevations at the same locations provides a quality assessment of the LIDAR data. A depiction of the quality control results, measured as a Root Mean Square Error (RMSE) in centimeters (cm), is provided at the right for the first phase of the Program.

North Carolina Phase I Status Map
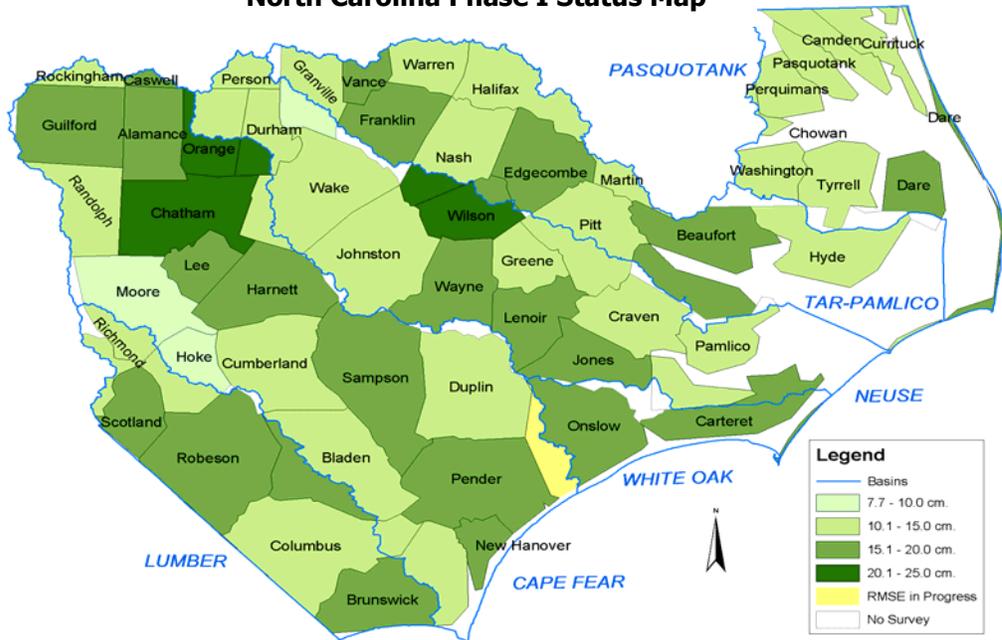
What are the Advantages of LIDAR?

The North Carolina Floodplain Mapping Program has chosen to use LIDAR to acquire new, highly accurate digital elevation data for floodplain mapping. Compared to traditional photogrammetric methods used to develop topographic data, LIDAR has several advantages, including:

- LIDAR is better able to map bare earth elevations in forested or vegetated areas than other methods because only a single laser pulse needs to be able to reach between trees and the ground.

- The post-spacing for digital elevation data derived from LIDAR is considerably denser than from traditional methods. For example, LIDAR data from eastern North Carolina have nominal point spacing of approximately 3 meters, whereas older methods typically acquire data points spaced at 10 to 30 meters.

- Digital elevation data created from LIDAR are considerably less expensive than those created from traditional methods, especially when automated post-processing is used to generate LIDAR bare earth elevation data.
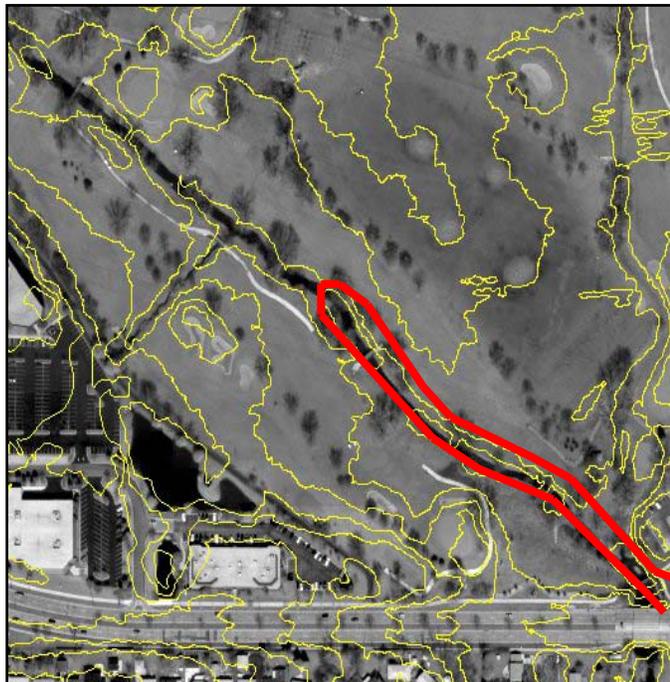
Floodplain Mapping

Because of the high density of mass points, LIDAR is superior for automated Hydrologic and Hydraulic (H&H) analyses and automated floodplain delineation such as that shown to the left, which is used to create Flood Insurance Rate Maps (FIRMs).

What are the Disadvantages of LIDAR?

Digital elevation data developed from any method, including LIDAR, are not perfect. LIDAR cannot accurately delineate stream channels, shorelines, or ridge lines visible on photographic images. In addition, because manual processing is required, contours derived from LIDAR are not normally hydro-corrected to ensure the downward flow of water in the digital elevation data. A comparison of human- and LIDAR-produced contours is shown from Chapter 13, *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, to the right. Contours derived automatically from LIDAR data (yellow contours) may depict stream channels differently than manual photogrammetric techniques (red contour). For many applications, the unedited LIDAR-derived contours may be acceptable. For applications where contours along a stream must depict continuous downhill flow, it is usually necessary to manually incorporate break lines along the stream channels, adding to project costs and delivery times.

Human Interpreted Contour (red) Versus LIDAR Derived Contours (yellow) without Smoothing

Available Digital Elevation Data Products

The North Carolina Floodplain Mapping Program has developed a dynamic information technology infrastructure, called the Floodplain Mapping Information System (FMIS). This was developed to maintain, archive, and disseminate flood maps and associated data, including digital elevation data and other framework data layers, to the public via the Internet. FMIS is available through the program's website at www.ncfloodmaps.com. A summary of the LIDAR elevation data being made available through FMIS is provided below. The digital datasets are in North American Datum of 1983 (horizontal) and North American Vertical Datum of 1988 (vertical) projections. Metadata has been developed for the archived digital elevation data in all formats given below.
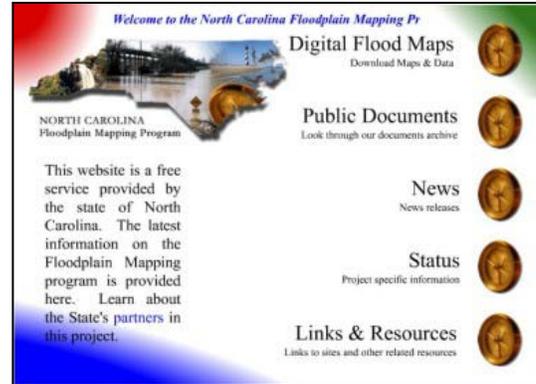
Product Name	Tile Size	File Format(s)	Metadata
Bare Earth Mass Points	10,000 feet	ASCII	Yes
Bare Earth Break Lines	10,000 feet	ESRI Shapefile	Yes
50-Foot Hydro-Corrected DEMs	10,000 feet	ESRI GRID, ASCII	Yes
20-Foot DEMs	10,000 feet	ESRI GRID, ASCII	Yes

The initial LIDAR dataset (i.e., mass points) is irregularly spaced. Regularly spaced Digital Elevation Models (DEMs) may be generated by interpolation between irregularly-spaced mass points that reflect the bare earth elevation where a LIDAR pulse hit the ground. An example of their distribution is shown below as red points. Areas covered by water create natural voids in LIDAR datasets (identified by green lines). Other voids (areas within white lines) are created during processing where LIDAR fails to penetrate dense vegetation. Points shown in yellow represent bare earth elevations, near shorelines, that are higher than surrounding points. These points are depicted to highlight how LIDAR data along streams may not accurately reflect decreasing elevations in the downstream direction. For this reason, bare earth break lines are developed and provided on FMIS. Mass points outside the stream's floodplain were omitted for clarity.

> **Digital Elevation Model (DEM)**: A popular acronym used as a generic term for digital topographic and/or bathymetric data in all its various forms.

Post-Processed, Bare-Earth LIDAR Mass Points along a North Carolina Stream

Void created during processing of LIDAR
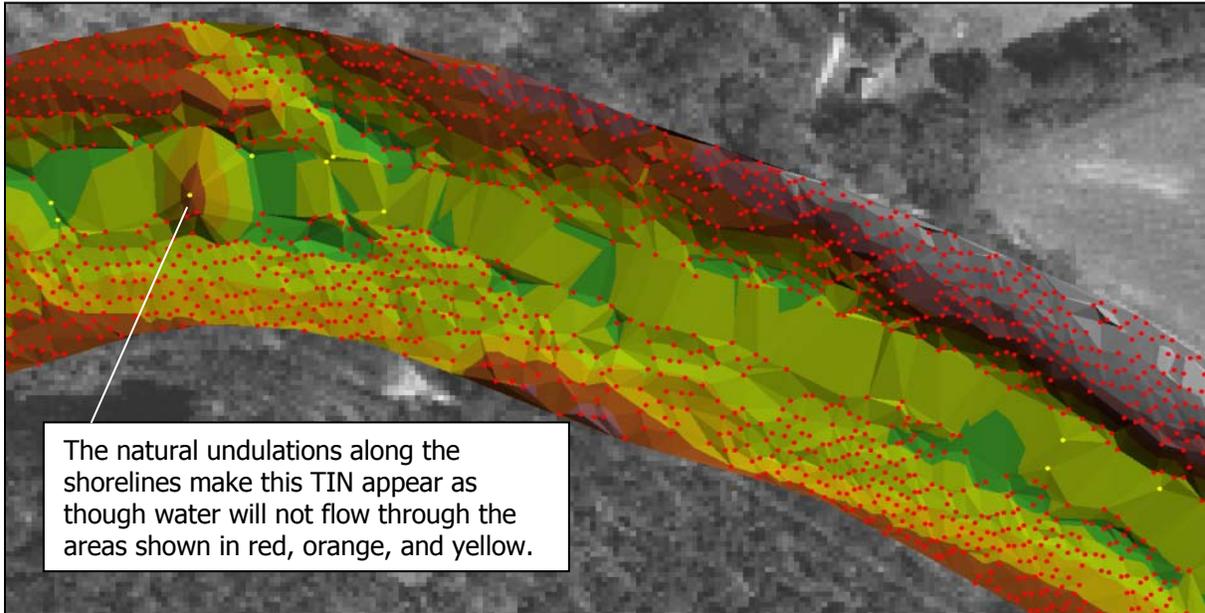
Void created due to surface water
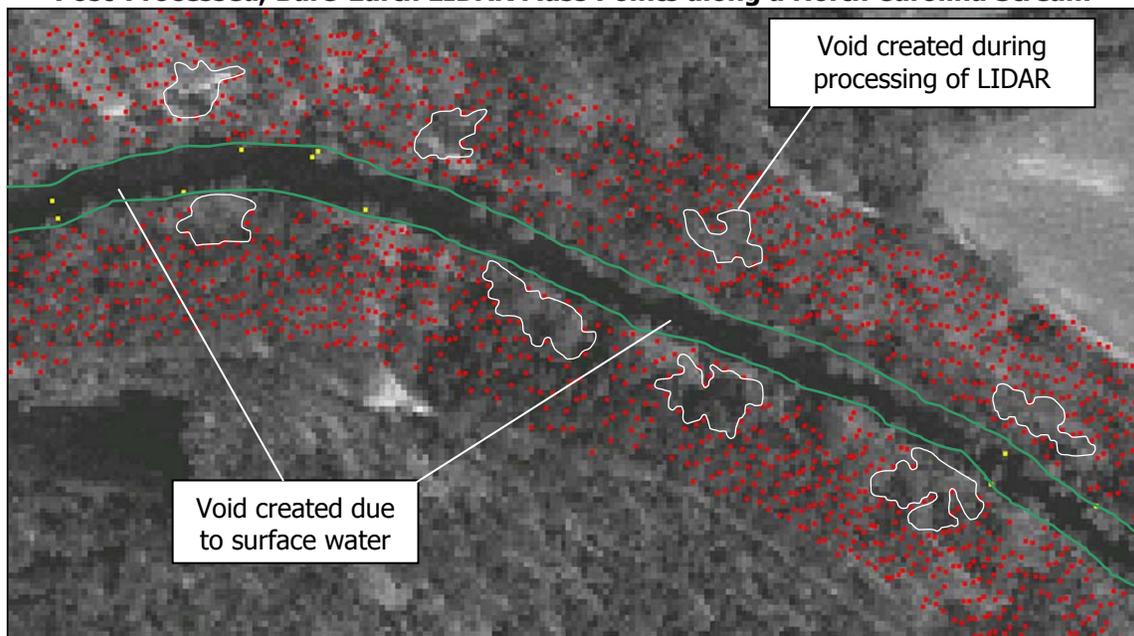
What Digital Elevation Data Products Can Users Generate?

Bare earth mass points and break lines can be used to create a representation of the ground surface called a Triangulated Irregular Network (TIN). This page depicts two visual examples of the same mass points shown on page 4. If only the mass points are converted into a TIN, the following surface is created.

> **Triangulated Irregular Network (TIN):** Set of adjacent, non-overlapping triangles computed from irregularly spaced points with x/y coordinates and z-values.

Geometric View of a TIN (Hillshaded by Elevation) Created Without Break Lines

The natural undulations along the shorelines make this TIN appear as though water will not flow through the areas shown in red, orange, and yellow.

Break lines (shorelines digitized from an orthophotograph in the following example) are represented in the TIN below along with an estimated stream centerline. This TIN is created using computer software from mass points and three-dimensional (3-D) break lines, which are available on FMIS. 3-D break lines are obtained by assigning z-values to 2-D break lines using elevation data (e.g., field surveyed cross sections).

Geometric View of a TIN (Hillshaded by Elevation) Created With Break Lines

Shorelines

Stream Centerline
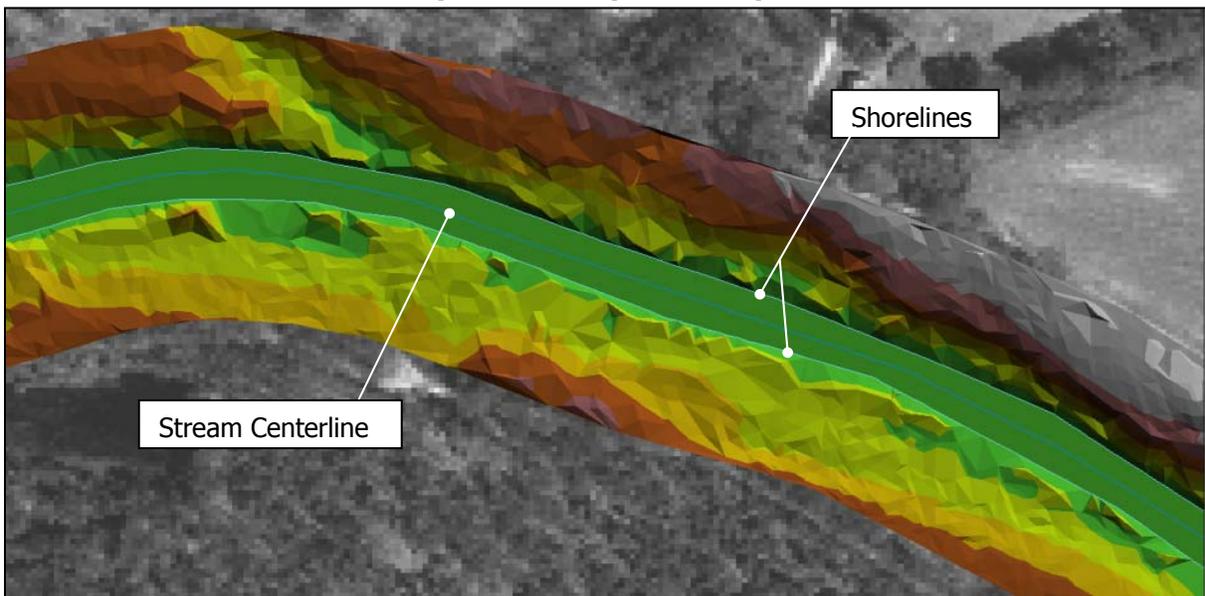
The State's program is not creating contour maps. Contours can be developed from any elevation dataset. However, users are cautioned that the accuracy of a contour map depends on the elevation data used.

Acronyms and Definitions*

Bare Earth: Digital elevation data of the terrain, free from vegetation, buildings, and other man-made structures. Elevations of the ground.

Break Line: A linear feature that describes a change in smoothness or continuity of a surface.

Contours: Lines of equal elevation on a surface. An imaginary line on the ground, all points of which are at the same elevation above or below a specified reference surface.

Datum: Any quantity or set of such quantities that may serve as a basis for calculation of other quantities. For digital elevation data produced under the North Carolina Floodplain Mapping Program, the horizontal datum (i.e., coordinate system in which horizontal control points are located) is the North American Datum of 1983 (NAD 83) and the vertical datum (i.e., set of constants defining a height system) is the North American Vertical Datum of 1988 (NAVD 88).

DEM (Digital Elevation Model): A popular acronym used as a generic term for digital topographic and/or bathymetric data in all its various forms, but most often bare earth elevations at regularly spaced intervals in x and y directions. Regularly spaced elevation data are easily and efficiently processed in a variety of computer uses.

DTM (Digital Terrain Model): Similar to DEMs, but they may incorporate the elevation of significant topographic features on the land and mass points and break lines that are irregularly spaced to better characterize the true shape of the bare earth terrain.

FIRM (Flood Insurance Rate Map): An official map of a community on which FEMA has delineated the flood hazard areas and the risk premium zones.

GIS (Geographic Information System): A system of spatially referenced information, including computer programs that store, manipulate, analyze, and display spatial data.

GPS (Global Positioning System): Technology that computes the three-dimensional position in space, for example the LIDAR sensor, using satellites.

H&H (Hydrologic & Hydraulic): The modeling of rainfall runoff (hydrology), providing peak discharges, and the resulting flow within a channel (hydraulics), which provides a profile of water surface elevations. Digital elevation data are used for H&H analyses.

Hillshade: A function used to create an illuminated representation of a surface, using a hypothetical light source, to enhance visualization effects.

IMU (Inertial Measurement Unit): Technology that computes the roll, pitch, and heading of a moving object, for example a LIDAR sensor.

LIDAR (Light Detection and Ranging): An instrument that measures distance to a reflecting object by emitting timed pulses of laser light and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to distance.

Mass Points: Irregularly spaced points, each with x/y location coordinates and z-value, typically (but not always) used to form a TIN. When generated by LIDAR, mass point spacing and pattern depend upon the characteristics of the technologies used to acquire the data and remove vegetation and man-made structures.

RMSE (Root Mean Square Error): An accuracy assessment for measured data (e.g., LIDAR) calculated by taking the square root of the average of the set of squared differences between dataset values (i.e., LIDAR derived elevations versus field surveyed elevations).

TIN (Triangulated Irregular Network): A set of adjacent, non-overlapping triangles computed from irregularly spaced points with x/y coordinates and z-values. A TIN model may be preferable to a DEM when it is critical to preserve the location of narrow or small surface features such as a stream channel or ridge line.

Vegetation Removal: Correction of surface elevations so as to depict the elevation of the bare earth terrain beneath the vegetation and man-made structures.

Voids: Portions of a digital elevation dataset where no elevation data are available.

* From Appendix A & B, *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, by the American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 2001.