Map
MODERNIZATION

Federal Emergency Management Agency

FEMA's Flood Hazard Mapping Program

Guidelines and Specifications *for* Flood Hazard Mapping Partners

Appendix A: Guidance for Aerial Mapping and Surveying

FEDERAL EMERGENCY MANAGEMENT AGENCY

http://www.fema.gov/fhm/dl_cgs.shtm

April 2003

Table of Revisions for Appendix A,

Guidance for Aerial Mapping and Surveying

The following Summary of Changes details revisions of Appendix A subsequent to the initial publication of the Guidelines in February 2002. These changes represent new or updated guidance for Flood Hazard Mapping Partners.

Date	Affected Section(s)	Summary of Change
April 2003	A.4.9	Deleted NIMA's Vector Product Format (VPF) and added MapInfo's native tabular format (TAB)
April 2003	A.4.11	In Table A-3, deleted VPF and added TAB
April 2003	A.8.3.1, A.8.7.2, A.8.7.3	Documented need for geoid model and ellipsoid used. This accommodates future changes to the geoid or ellipsoid

Appendix A

Guidance for Aerial Mapping and Surveying

A.1 Introduction [February 2002]

This Appendix presents Federal Emergency Management Agency (FEMA) aerial mapping and surveying guidelines and specifications that have been established to specify the quality of the spatial data products to be produced, including work maps and base maps used in the production of Flood Insurance Rate Maps (FIRMs), Digital Flood Insurance Rate Maps (DFIRMs), and DFIRM-Digital Line Graphs (DFIRM-DLGs). The term "FIRM" is used generically hereinafter to specify this "family" of FEMA spatial products.

This Appendix also includes guidance for ground surveys of control points, cross sections, and hydraulic structures, and for topographic mapping using photogrammetry, LIght Detection and Ranging (LIDAR), or other airborne remote-sensing technologies consistent with FEMA and industry standards.

A.1.1 Base Maps [February 2002]

A FIRM base map is a planimetric map, in digital or hardcopy format, showing the georeferenced horizontal location of mapped features, without depiction of elevation data such as contour lines. Georeferencing means that the map depicts the spherical earth projected as a plane map, normally with Universal Transverse Mercator (UTM) or State Plane coordinates, with or without tick marks or lines that depict parallels (lines of equal latitude) or meridians (lines of equal longitude). Base maps may be categorized as either vector maps or raster image maps, depending on how they are produced.

Vector maps result from linear features (e.g., roads, railroads, streams) digitized as single-line centerlines or, alternatively, as dual-lines showing the outer extremities of linear features (e.g., left and right banks of streams, curb lines on both sides of streets). Vector maps are digitized in such a way that a Geographic Information System (GIS) can automatically derive intelligence from the vector features and perform analyses (e.g., adjacency analyses, proximity analyses, and connectivity analyses).

Raster image maps result from digital scanning of paper maps, map negatives, aerial photographs, and orthorectification of those images so that they are accurately georeferenced with distortions removed. Raster image maps rely on human interpretation of scanned or imaged features to derive intelligence therefrom. The most common form of raster image map is the digital orthophoto, especially the standard Digital Orthophoto Quadrangle (DOQ) produced by the U.S. Geological Survey (USGS).

For a more detailed discussion of FIRM base maps, see Appendix K of these Guidelines.

A.1.2 Work Maps [February 2002]

FIRM work maps are discussed in Volume 1, Subsection 1.4.2.3, as part of the discussion of requirements for flood hazard analyses performed as part of a Flood Map Project.

A.1.3 Manual and Automated Analysis Procedures [February 2002]

A distinction is made in this Appendix between manual and automated hydrologic and hydraulic analysis procedures. Manual procedures rely on maps with contours for human interpretation and a relatively small number of cross sections selected to be representative of average conditions in reaches that are as long as possible without permitting excessive conveyance change between cross sections. Automated procedures normally use high-density elevation points (in lieu of contours) and computer generation of a potentially larger number of cross sections representative of shorter reaches.

A.2 Industry Geospatial Standards **[February 2002]**

In 1998, the Federal Geographic Data Committee (FGDC) published *Geospatial Positioning Accuracy Standards*, which replaced both the *United States National Map Accuracy Standards* (NMAS) published by the Office of Management and Budget in 1947 (Office of Management and Budget, 1947) and the American Society for Photogrammetry and Remote Sensing (ASPRS) *ASPRS Accuracy Standards for Large-Scale Maps* (ASPRS, 1990). Designed specifically for digital spatial data products, this new FGDC standard has three parts:

- Part 1, Reporting Methodology (FGDC-STD-007.1-1998)
- Part 2, Standards for Geodetic Networks (FGDC-STD-007.2-1998); and
- Part 3, National Standard for Spatial Data Accuracy (FGDC-STD-007.3-1998)

FGDC-STD-007.1-1998 provides a common methodology for reporting the accuracy of horizontal and vertical coordinate values of digital geospatial products. Specifically, the reporting standard in the horizontal component ($Accuracy_r$) is the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95 percent of the time. The reporting standard in the vertical component ($Accuracy_z$) is a linear uncertainty value, such that the true or theoretical location of the point falls within plus or minus of that linear uncertainty value 95 percent of the time. It also defines the meanings of "local accuracy" and "network accuracy" and other terms used in the FGDC standard. Part 1 of the *Geospatial Positioning Accuracy Standards* is available online at: www.fgdc.gov/standards/documents/standards/chapter1.pdf.

FGDC-STD-007.2-1998 provides a common methodology for determining and reporting the accuracy of horizontal and vertical coordinate values for geodetic control points represented by survey monuments, such as brass disks and rod marks. It provides a means to directly compare the accuracy of coordinate values obtained by one method (e.g., a classical line-of-sight traverse) with the accuracy of coordinate values obtained by another method (e.g., a Global Positioning System [GPS] geodetic network survey) for the same point. It explains how “network accuracy” is achieved by properly connecting survey and mapping data to control points in the National Spatial Reference System (NSRS). Part 2 of the *Geospatial Positioning Accuracy Standards* is available on the FGDC website at www.fgdc.gov/standards/documents/standards/chapter2.pdf.

FGDC-STD-007.3-1998 implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. If errors have a normal distribution and if systematic errors have been eliminated as best as possible, the National Standard for Spatial Data Accuracy (NSSDA) uses root-mean-square error (RMSE) to estimate positional accuracy of x, y and z coordinates ($RMSE_x$, $RMSE_y$ and $RMSE_z$ respectively). FGDC-STD-007.3-1998 defines RMSE as the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points and it defines (horizontal) radial accuracy in terms of $RMSE_r$ computed as a function of $RMSE_x$ and $RMSE_y$. FGDC-STD-007.3-1998 provides NSSDA testing guidelines, it relates $Accuracy_r$ and $Accuracy_z$ (horizontal and vertical accuracies at the 95-percent confidence level) to $RMSE_r$ and

$RMSE_z$, and it documents the statistical relationship between the NSSDA and the prior National Map Accuracy Standard (NMAS) and ASPRS 1990 standards. FGDC-STD-007.3-1998 is available online at www.fgdc.gov/standards/documents/standards/chapter3.pdf.

Other industry standards relevant to this Appendix are included in the following publications:

- National Oceanic and Atmospheric Administration (NOAA), Technical Memorandum NOS NGS-58, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm), version 4.3* (NOAA, 1997), which is available online at www.ngs.noaa.gov/PUBS_LIB/NGS-58.html and is referred to hereinafter as "NGS-58;"

- *Digital Elevation Model Technologies and Applications: The DEM Users Manual* (ASPRS, 2001);

- *ASPRS Draft Aerial Photography Standards*, "Photogrammetric Engineering & Remote Sensing" (ASPRS, 1995);

- U.S. Army Corps of Engineers (USACE) Engineer Manual 1110-1-1000, *Photogrammetric Mapping* (USACE, 2002); and

- USACE Engineer Manual 1110-2-1003, *Hydrographic Surveying* (USACE, 1994).

A.3 Accuracy Guidelines **[February 2002]**

For decades, when topographic maps were produced photogrammetrically and printed in hardcopy form, users became accustomed to specifying map requirements in terms of the published *map scale* and *contour interval*. Users generally understood the meaning of those terms, and photogrammetrists had well-established procedures for determining the flying height, forward overlap and sidelap, aerial triangulation, and map compilation procedures necessary to consistently produce a map to the required map scale and contour interval, in conformance with the National Map Accuracy Standard (NMAS).

With the new NSSDA designed for digital geospatial data, the defining parameters are much more complex. What once had been a simple standard printed on one page (i.e., the NMAS) has become a complex standard (i.e., the NSSDA) that is nearly one inch thick. The more complex standard was necessary to accommodate the variables and options available with digital geospatial data and the increased complexity of digital data that are subject to use in many different ways.

FEMA has chosen to define its digital topographic data accuracy requirements in terms of map scale and contour interval *equivalent* to NMAS terminology, but also cross-referenced to radial root-mean-square-error ($RMSE_r$) and/or $Accuracy_r$ (to define horizontal accuracy at the 95-percent confidence level), and $RMSE_z$ and/or $Accuracy_z$ (to define vertical accuracy at the 95-percent confidence level) as defined by the NSSDA, assuming the errors have a normal distribution. The NSSDA does not cover what to do when errors do not follow a normal distribution, as is often the case with LIDAR datasets. In Chapter 12, "DEM Quality Assessment" of *Digital Elevation Model Technology and Applications: The DEM Users Manual* (ASPRS, 2001), the ASPRS proposes a 5-step approach that includes the use of the 95^{th} percentile error as the next best method for estimating $Accuracy_z$ when it is determined (through statistical "outliers," discussed in Section A.8.3.1) that checkpoint errors do not follow a normal distribution.

As shown in Tables A-1 and A-2, these NMAS and NSSDA terms are also cross-referenced to ASPRS, 1990 Class 1, Class 2, and Class 3 standards, which are terms still used by the industry. To simplify the terminology, FEMA has reduced the complex requirements to two standard choices for digital elevation data, expressed as equivalent contour intervals:

- Two-foot equivalent contour interval for flat terrain ($Accuracy_z$ = 1.2 foot at the 95-percent confidence level). This means that 95 percent of the elevations in the dataset will have an error with respect to true ground elevation that is equal to or smaller than 1.2 feet.

- Four-foot equivalent contour interval for rolling to hilly terrain ($Accuracy_z$ = 2.4 ft at the 95-percent confidence level.) This means that 95 percent of the elevations in the dataset will have an error with respect to true ground elevation that is equal to or smaller than 2.4 feet.

The FEMA Lead for a Flood Map Project—usually, the Regional Project Officer (RPO) or the Project Officer (PO) at FEMA Headquarters—may select non-standard alternatives when valid and compelling reasons for specifying other accuracy standards exist.

A.3.1 Horizontal Accuracy Criteria **[February 2002]**

Several accuracy standards are still in use today for the mapping industry. The following is a description and comparison of the different standards used and which apply.

The NMAS (Bureau of the Budget, 1947) states:

> Horizontal accuracy: For maps on publication scales larger than 1:20,000, not more than 10% of the points tested shall be in error by more than $1/30^{th}$ of an inch, measured on the publication scale.

This 1/30-inch standard for large-scale maps is called the Circular Map Accuracy Standard (CMAS). The NMAS became obsolete for digital mapping products because computers can easily change the scale of a map, and maps do not become more accurate just because the computer enables users to "zoom in" on the map to display it at a larger scale.

To prevent abuse of digital mapping data, the mapping industry operated during much of the 1990s under ASPRS 1990 standards. ASPRS 1990 standards established limiting RMSEs for three classes of maps (Class 1, Class 2, Class 3), along with typical map scales associated with the limiting errors. Three times the "limiting RMSE" was essentially a 100-percent confidence level standard.

In 1998, the FGDC published the NSSDA, which superseded both the NMAS and the ASPRS 1990 standards for digital mapping products. NSSDA implemented a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. Radial RMSE ($RMSE_r$) calculations were established, and radial accuracy ($Accuracy_r$) at the 95-percent confidence level was established as 1.7308 x $RMSE_r$. $Accuracy_r$ is defined as "the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95-percent of the time." NSSDA specifies horizontal errors at the 95-percent confidence level, whereas the NMAS specified horizontal errors at the 90-percent confidence level, and ASPRS 1990 specified horizontal errors at nearly the 100-percent confidence level. When assuming all horizontal errors have a normal distribution, the NSSDA/NMAS conversion factor is as follows:

$$Accuracy_r = CMAS \times 1.1406.$$

With NSSDA, $RMSE_r$ is defined in terms of feet or meters at ground scale rather than in inches or millimeters at the target map scale. The $RMSE_r$ of a DFIRM panel is the cumulative result of all errors, including those introduced by Mapping Partners in performing ground surveys, aerial triangulation, map compilation, and digitization activities. The $RMSE_r$ and $Accuracy_r$ values shown in Table A-1 are the maximum permissible values established by NSSDA for base maps compiled at 1"=500' and 1"=1000' under NMAS. Table A-1 serves as a "crosswalk" between the NMAS, NSSDA, and ASPRS 1990 horizontal accuracy standards. Note that $RMSE_r$ = square root of ($RMSE_x^2 + RMSE_y^2$).

Table A-1. Comparison of Horizontal Accuracy Standards

NMAS Map Scale	**NMAS** CMAS 90% confidence level	**NSSDA** $Accuracy_r$ 95% confidence level	**NSSDA** $RMSE_r$	**ASPRS 1990** Class 1/2/3 Limiting $RMSE_r$
1" = 500'	16.7 feet	19.0 feet	11.0 feet	7.1 feet (Class 1) 14.1 feet (Class 2) 21.2 feet (Class 3)
1" = 1,000'	33.3 feet	38.0 feet	22.0 feet	14.1 feet (Class 1) 28.3 feet (Class 2) 42.4 feet (Class 3)
1" = 2,000'	40.0 feet	45.6 feet	26.3 feet	28.3 feet (Class 1) 56.5 feet (Class 2) 84.9 feet (Class 3)

Thus, when FEMA specifies a base map at 1" = 500', for example, this is the same as FEMA specifying that a digital base map should have a horizontal (radial) $RMSE_r$ of 11 feet or $Accuracy_r$ of 19 feet at the 95-percent confidence level, for consistency with the new NSSDA.

When a base map is compiled at 1"=1,000' and is published at a hardcopy map scale of 1"=500', the horizontal accuracy remains that of the 1"=1,000' map scale. Therefore, such a 1"=500' map would be compiled to meet 38-foot horizontal accuracy at 95-percent confidence level, rather than 19-foot horizontal accuracy at 95-percent confidence level as is normally expected of maps published at a scale of 1"=500'. This is an example where "zooming in" on a map image does not make the map any more accurate.

A.3.2 Vertical Accuracy Criteria **[February 2002]**

Several standards for computing vertical accuracy also are in use by the mapping industry. These are discussed and compared below.

The NMAS (Bureau of the Budget, 1947) states:

> Vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

This one-half contour interval under NMAS is called the Vertical Map Accuracy Standard (VMAS). NMAS became obsolete for digital mapping products because computers can easily change the scale and contour interval of a map, and maps are not more accurate because the computer can take 10-foot contours, for example, and regenerate 5-, 2- or 1-foot contours for higher resolution display purposes.

Under ASPRS 1990 standards, which were used during much of the 1990s, the mapping industry operated with vertical RMSEs equal to one-third of the contour interval for ASPRS Class 1 maps, two-thirds of the contour interval for ASPRS Class 2 maps, and full contour interval for ASPRS Class 3 maps. Again, three times the limiting $RMSE_z$ was a standard at almost the 100-percent confidence level (99.75-percent).

In 1998, NSSDA also superseded both the NMAS and ASPRS 90 vertical accuracy standards for digital mapping products. Vertical RMSE ($RMSE_z$) calculations were established, and vertical accuracy ($Accuracy_z$) at the 95-percent confidence level was established as 1.9600 x $RMSE_z$ when errors follow a normal distribution. $Accuracy_z$ is defined as "the linear uncertainty value, such that the true or theoretical location of the point falls within $\pm$ of that linear uncertainty value 95-percent of the time." Again, note that NSSDA specifies vertical errors at the 95-percent confidence level whereas NMAS specified vertical errors at the 90-percent confidence level, and the ASPRS 1990 specified vertical errors at nearly the 100-percent confidence level. When assuming all vertical errors have a normal distribution, the NSSDA/NMAS conversion factor is as follows:

$$Accuracy_z = VMAS \times 1.1916$$

Contrary to NMAS, NSSDA does not specifically state that the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error.

With NSSDA, $RMSE_z$ is defined in terms of feet or meters at ground scale rather than in terms of the contour interval of the published map. The $RMSE_z$ and $Accuracy_z$ values shown in Table A-2 are the maximum permissible values established by the NSSDA for digital elevation data equivalent to maps compiled with 2-foot and 4-foot contours compiled under NMAS. Table A-2 serves as a "crosswalk" between the NMAS, NSSDA and ASPRS 1990 vertical accuracy standards. This comparison is only statistically valid, however, when vertical errors have a normal distribution.

Thus, when FEMA specifies 2-foot contour interval mapping, for example, this is the same as specifying that digital topographic data, regardless of whether the data are digital contours, mass points and breaklines, Triangulated Irregular Networks (TINs), or Digital Elevation Models (DEMs), should have vertical $RMSE_z$ of 0.6 foot (18.5 centimeters) or $Accuracy_z$ of 1.2 feet (37 centimeters) at the 95-percent confidence level, for consistency with the NSSDA.

Table A-2. Comparison of Vertical Accuracy Standards

NMAS Contour Interval	NMAS VMAS 90% confidence level	NSSDA $Accuracy_z$ 95% confidence level	NSSDA $RMSE_z$	ASPRS 1990 Class 1/2/3 Limiting $RMSE_z$
2 feet	1 foot	1.2 feet	0.6 foot 18.5 centimeters	0.7 foot (Class 1) 1.3 feet (Class 2) 2.0 feet (Class 3)
4 feet	2 feet	2.4 feet	1.2 feet 37.0 centimeters	1.3 feet (Class 1) 2.7 feet (Class 2) 4.0 feet (Class 3)

A.3.3 Accuracy Labeling **[February 2002]**

Because contours or DEMs are not printed on DFIRMs, their vertical accuracy does not need to be labeled on DFIRMs, but the vertical accuracy is still recorded in the metadata of elevation datasets used for hydrologic and hydraulic modeling. If tested to a vertical RMSE of 0.6 foot (18.5 centimeters), for example, and recognizing that $Accuracy_z = 1.9600 \times RMSE_z$ when errors have a normal distribution, the metadata would read as follows:

Tested 1.2-foot vertical accuracy at 95-percent confidence level

DFIRMs published at 1”=500’ scale with community-provided base maps or digital orthophotos compiled at 1”=500’ or smaller scales (e.g., 1”=400’, 1"=200’, and 1"=100’) would be labeled as follows:

Compiled to meet 19-foot horizontal accuracy at 95-percent confidence level

DFIRMs published at either 1”=500’ or 1”=1,000’ with default USGS DOQs, compiled at 1”=1000’, would be labeled as follows:

Compiled to meet 38-foot horizontal accuracy at 95-percent confidence level

Similarly, DFIRMs published at 1"=2,000' would be labeled as follows:

Compiled to meet 45.6-feet horizontal accuracy at 95-percent confidence level

A.4 Data Requirements **[February 2002]**

Requirements for topographic mapping, cross sections, and hydraulic structure surveys will vary from Flood Map Project to Flood Map Project, depending on the flood hazard being addressed (e.g., riverine, coastal, alluvial fan) and the option that is selected for generating flood hazard data. Detailed information on the options for generating flood hazard data is presented in Volume 1, Section 1.4 and in Appendix C of these Guidelines.

New flood hazard data may be generated through detailed or approximate analyses. Updated flood hazard data may be developed through detailed or approximate analyses or redelineation of floodplain boundaries from the effective FIRM using more up-to-date and/or more accurate topographic data than were used to prepare the effective FIRM. The topographic mapping, cross section, and hydraulic survey requirements for each analysis option are summarized below.

- For a *detailed flood hazard analysis,* which will generally include a detailed hydraulic analysis, digital topographic data, cross sections (to include underwater elevations), and surveys of hydraulic structures are required. Ground surveys and either photogrammetric mapping or LIDAR-generated mapping are normally required unless suitable topographic information is already available from other sources.

- For an *approximate flood hazard analysis*, cross sections may be interpolated from contours on topographic maps, and underwater elevations may be interpolated from upstream/downstream data, assuming the channel bottom information has not changed significantly. Hydraulic structure surveys are not required.

- For a *redelineation of floodplain boundaries using more up-to-date or more accurate topographic data,* the topographic data needed to update the floodplain boundaries are required, but no new cross sections or hydraulic structure surveys are required.

The requirements summarized in this Appendix are based on the assumption that suitable data do not exist from alternative sources and that new ground/aerial surveys will be required.

A.4.1 Map Scale of DFIRMs and Base Maps **[February 2002]**

Detailed information on how DFIRM map scales are determined is presented in Appendix K of these Guidelines.

A.4.2 Data Models and Surfaces **[February 2002]**

Mapping Partners may produce digital elevation datasets in many forms. For purposes of the National Flood Insurance Program (NFIP), the default surface is the bare-earth terrain, devoid of vegetation and manmade structures. The FEMA Lead for the Flood Map Project (usually, the Regional Project Officer (RPO) or Project Officer (PO) at FEMA Headquarters) may specify the use of one or more of the following data models:

- Digital contours;

- Mass points;
- Breaklines;
- TINs; and
- DEMs

These models are discussed in Subsections A.4.2.1 through A.4.2.5.

A.4.2.1 Digital Contours [February 2002]

Digital contours, or hardcopy plots of such contours, are normally used in manual hydrologic and hydraulic analyses. Contours normally depict breakline features of interest to hydraulic engineers.

A.4.2.2 Mass Points [February 2002]

LIDAR produces irregularly spaced mass points. "First-return" LIDAR data provide elevation mass points on reflective surfaces (e.g., treetops, rooftops, towers). "Last-return" LIDAR data provide elevation mass points of the bare-earth terrain, but only after successful completion of automated and manual post processing for vegetation removal and cleaning (removal) of manmade features and artifacts. Mass points can also be produced when using photogrammetric methods.

A.4.2.3 Breaklines [February 2002]

Breaklines are linear features that describe a change in the slope, smoothness, or continuity of a surface. "Soft breaklines" ensure that known z-values along a linear feature are maintained, and they ensure that linear features and polygon edges are maintained in a TIN surface model, by enforcing the breakline as TIN edges; but, they do not define interruptions in surface smoothness. "Hard breaklines," which define interruptions in surface smoothness, are used to define streams, shorelines, dams, ridges, building footprints, seawalls, and other locations with abrupt surface changes. Automated techniques for generating digital elevation data, from LIDAR data for example, normally do not generate breaklines well.

Breaklines are best produced either by stereo photogrammetric procedures, where three-dimensional breaklines are produced (coordinate line strings having x/y/z coordinates), or digital orthophotography, where shorelines, stream centerlines, and other breakline features are digitized as two-dimensional breaklines (i.e., coordinate line strings having x/y coordinates but no z-values). Regardless of the technology used, the Mapping Partner shall normally produce breaklines for stream centerlines, drainage ditches, tops and bottoms of streambanks, ridge lines, road crowns, levees, bulkheads, seawalls, road/highway embankments, and selected manmade features that constrict or control the flow of water (e.g., curb lines). The Mapping Partner also shall specify the sources and accuracy of breakline data.

A.4.2.4 Triangulated Irregular Networks [February 2002]

A TIN is a set of adjacent, non-overlapping triangles, computed from irregularly spaced points with x/y coordinates and z-values. The TIN data structure is based on irregularly spaced point, line, and polygon data interpreted as mass points and breaklines. The TIN model stores the topological relationship between triangles and their adjacent neighbors (i.e., which points define each triangle and which triangles are adjacent to each other). This data structure allows for the efficient generation of surface models for the analysis and display of terrain and other types of surfaces while preserving the continuous structure of features such as levees and streambanks that are critical in hydrologic and hydraulic analyses.

Because breakline information is important for hydraulic analyses, TINs are normally required for floodplains and surrounding buffer zones where automated hydraulic analyses and modeling are performed. TINs are also ideal for performing independent Quality Assurance/Quality Control (QA/QC) reviews, because TIN surfaces are easily interpolated to determine elevation z-values at checkpoint x/y coordinates that fall somewhere between the TIN triangle corners.

A.4.2.5 Digital Elevation Models (DEMs) [February 2002]

DEMs model the elevation of the land (z-values) at regularly spaced intervals in x and y directions (eastings and northings). DEMs are usually displayed as uniformly spaced grids. Because of the uniform point spacing, DEMs can "jump over" breaklines without identifying ditches, stream centerlines, steep banks, and other similar features. However, DEMs are simple data models, easy to store, and suitable for automated hydrologic analyses and modeling where breakline information is unimportant.

DEMs are normally produced by interpolation from surrounding mass points or TIN corners. DEMs are normally required for entire watersheds, for which automated hydrologic analyses and modeling will be performed. Because they are interpolated, DEMs are slightly less accurate than the TINs, mass points, or breaklines from which they are derived.

A.4.3 Vertical Accuracy [February 2002]

As explained in Section A.3, one of the fundamental requirements that the FEMA Lead must establish is to which of the following standards the digital topographic data will be compiled:

- Standard 2-foot equivalent contour interval accuracy ($Accuracy_z$ = 1.2 foot) appropriate for flat terrain;

- Standard 4-foot equivalent contour interval accuracy ($Accuracy_z$ = 2.4 foot) appropriate for rolling to hilly terrain; or

- Some alternative standard.

The specified accuracy of FIRM work maps produced by Mapping Partners must be sufficient to ensure that the final FIRMs produced by FEMA can be reliably used for the purpose intended. However, the accuracy and resolution requirements of a mapping product must not surpass that required for its intended functional use. Specifying map accuracies in excess of those required results in increased costs, delays in project completion, and reduction in the total numbers of new or revised products that the Mapping Partner may generate. Mapping accuracy requirements must originate from functional and realistic accuracy requirements.

A.4.3.1 Vertical Accuracy as a Function of Horizontal Accuracy [February 2002]

The vertical accuracy of mass points, TINs, or DEMs also is a function of horizontal accuracy because NMAS traditionally has allowed apparent vertical errors to be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale. As indicated in Table A-1, according to NMAS, 90 percent of horizontal test points are to be accurate within 16.7 feet for maps published at a scale of 1" = 500', the most common scale for DFIRM panels. This equates to a horizontal (radial) RMSE ($RMSE_r$) of 11.0 feet.

Nevertheless, LIDAR vendors normally advertise that their systems deliver data with an $RMSE_r$ of 1 meter or less. This horizontal accuracy is difficult to verify, except for calibration test ranges, where coordinates of the four corners of rooftops of several buildings are accurately surveyed (in addition to ground control points) and compared with LIDAR calibration flights flown over the calibration area from the four cardinal directions (north, south, east, west). The horizontal accuracy with which these building breaklines can be determined provides a good estimate of the overall horizontal accuracy of LIDAR datasets obtained under similar conditions.

A.4.3.2 Vertical Accuracy as a Function of Horizontal Resolution [February 2002]

The vertical accuracy of mass points, TINs, or DEMs also is a function of the horizontal resolution of the digital topographic data. Horizontal resolution refers to the average point spacing of irregularly spaced mass points (from LIDAR, for example) or uniformly spaced DEM points, and is more commonly known as the DEM "post spacing." To provide multiple surrounding points for interpolation of DEM elevation posts, the horizontal resolution of mass points normally is narrower than the DEM resolution. For example, to derive a DEM with uniform post spacing of 5 meters, it is common for LIDAR dataset mass points to have average post spacings of 3 to 4 meters, a denser dataset from which some points will be eliminated as a result of post-processing to remove points that impinged on manmade structures or dense vegetation.

No established rules directly correlate the horizontal resolution of digital elevation data with vertical accuracy, even though there is general agreement that TINs or DEMs equivalent to 2-foot contours ought to have narrower post spacing than TINs or DEMs equivalent to 4-foot contours. Cartographers typically associate map scale with contour interval as follows:

- Maps compiled at 1"=100' with 1-foot contours need DEM post spacing of 1 meter
- Maps compiled at 1"=200' with 2-foot contours need DEM post spacing of 2 meters
- Maps compiled at 1"=500' with 5-foot contours need DEM post spacing of 5 meters
- Maps compiled at 1"=1,000' with 10-foot contours need DEM post spacing of 10 meters
- Maps compiled at 1"=2,000' with 20-foot contours need DEM post spacing of 20 meters.

USGS 7.5-minute-series topographic quadrangle maps are generally prepared at a scale of 1"=2,000', and DEMs have traditionally been produced by USGS with post spacing of 30 meters. However, new standard USGS DEMs, produced from the contour lines on quadrangle maps, are being produced with 10-meter post spacing. Depending on the ruggedness of the terrain, the USGS may have compiled these quadrangle maps with contour intervals of 5, 10, 20, or 40 feet—all published at a scale of 1"=2,000'. Thus, no rigid rules that link DEM resolution to map scale or contour interval exist.

However, mass points and breaklines, or TINs derived therefrom, are typically used for hydraulic modeling. When breakline data are available (e.g., at the tops and bottoms of streambanks), the average mass point or DEM post spacing can be wider than indicated above. For example, if Mapping Partners are producing DFIRM work maps in flat terrain with digital topographic data equivalent to 2-foot contours, 2-meter post spacing may be appropriate if no supplemental breaklines are provided, but 5-meter post spacing is appropriate if supplemental breaklines are provided.

A.4.4 File Size, Tile Size, and Buffers [February 2002]

The size of the data file will have an effect on how well the Mapping Partner will be able to manage and manipulate the DEM or TIN. File size could have limiting factors, such as data storage, transfer media size, and software limitations. A DEM file with 2-meter post spacing will be 6.25 times larger than a DEM file with 5-meter post spacing; the same ratio applies to the average point spacing of mass points and TINs. File sizes must not exceed 1 gigabyte unless otherwise specified by the FEMA Lead.

In some cases, Mapping Partners may choose to limit files by "tile" size (e.g., 10,000-meter x 10,000-meter tiles, 5,000-meter x 5,000-meter tiles) by DFIRM panel size, by USGS DOQ size, or by the size of community-provided base maps. Depending on the horizontal resolution of data within these "tiles," the file sizes will vary.

Supplemental to the exact tile size, a buffer surrounding the tile may be required in the event that individual tiles are to be mosaicked together. Due to the interpolation and extrapolation at tile edges, single tiles may not "fit" adjoining tiles without overlapping buffers. For these reasons, a buffer zone equal to five percent of the tile size must be incorporated around adjoining tiles so that a seamless interpolation will occur between them. No new data are required as a result of buffering, but file sizes for individual tiles with such buffers will be 5 percent larger than without such buffers.

A.4.5 Mapping Area [February 2002]

High-accuracy digital elevation data are not required for hydrologic analyses. If no better form of digital elevation data is available, Mapping Partners may use USGS "off-the-shelf" DEMs for hydrologic analyses and modeling of entire watersheds. A Mapping Partner can purchase an off-the-shelf DEM from the USGS at a nominal cost.

Hydraulic analyses require high-accuracy contours, mass points and breaklines, TINs, or DEMs, but of floodplain areas only, and not of entire watersheds. The area to be mapped normally consists of the projected 0.2-percent-annual-chance (500-year) floodplain, plus a specified buffer of 1,000 feet beyond the 0.2-percent-annual-chance floodplain, as shown in Figure A-1. Although data for the entire study area normally are acquired by an aerial survey contractor using photogrammetric methods or LIDAR, only the polygon areas within the projected 0.2-percent-annual-chance floodplain and buffer zones are to be processed to produce the high-accuracy elevation data required for hydraulic analyses.

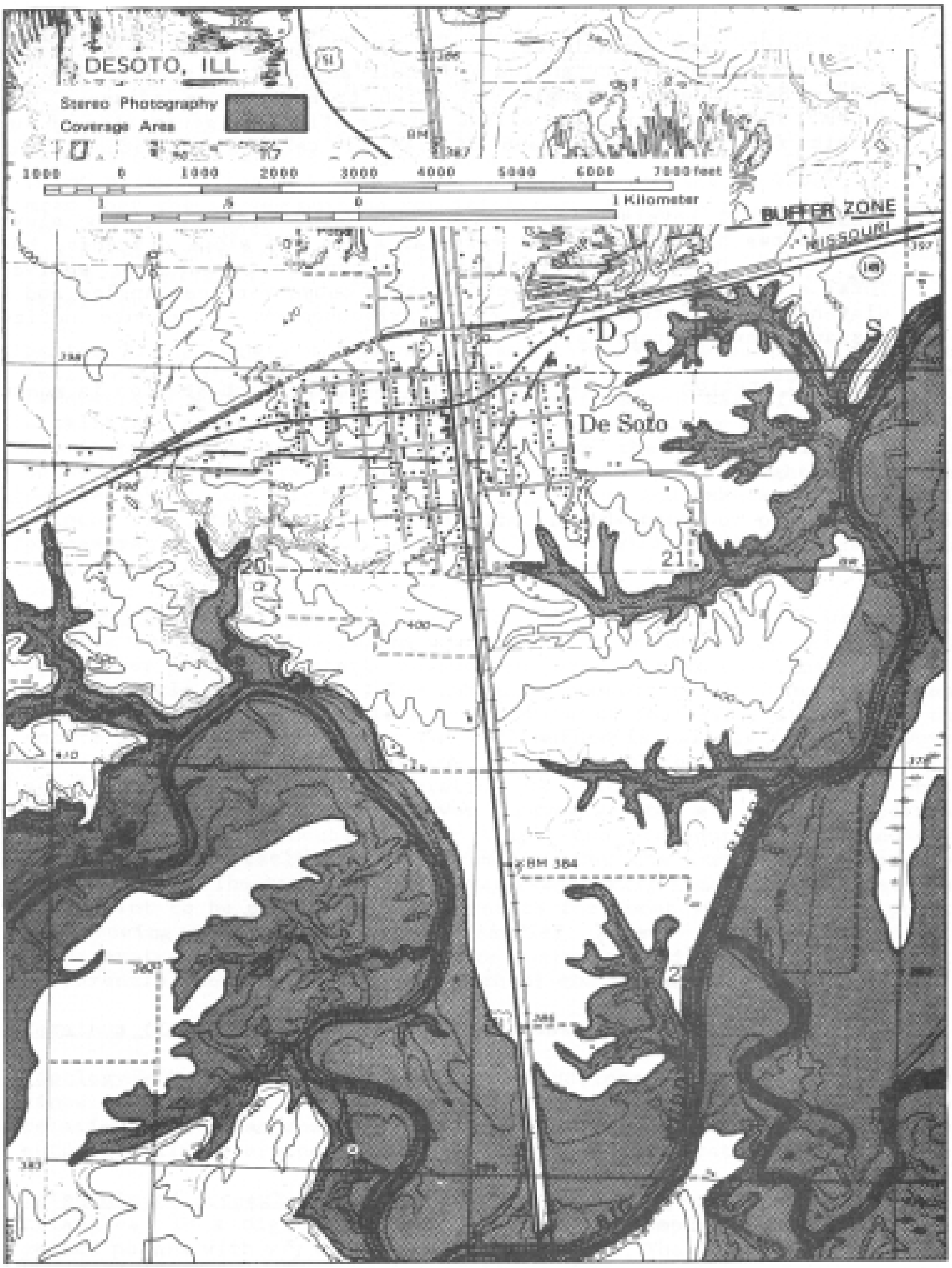

Figure A-1. Sample Location Map

A.4.6 Cross Sections **[February 2002]**

For detailed flood hazard analyses, the assigned Mapping Partner shall survey cross sections immediately upstream and downstream of bridges and culverts, using field survey methods, to include survey of channel invert elevations (the elevation at the deepest part of a channel cross section). The Mapping Partner shall survey intermediate cross sections when bridges or culverts are more than 1,000 feet apart, especially where a significant change in conveyance occurs between cross sections. The Mapping Partner may "cut" intermediate cross sections from stereophotogrammetric models or from LIDAR datasets so long as no significant change in the stream channel geometry below the water level occurs. When flooding sources have little change in conveyance, the Mapping Partner may determine whether fewer cross sections are needed. The Mapping Partner shall determine cross-section elevations and stations at those points that represent significant breaks in ground slope and at changes in the hydraulic characteristics of the floodplain. The Mapping Partner shall ensure that each cross section crosses the entire 0.2-percent-annual-chance floodplain.

For hydrologic and hydraulic analyses performed using manual techniques, the assigned Mapping Partner shall select ground surveyed or photogrammetric cross section locations carefully to ensure they are representative of reaches that are as long as possible, without permitting excessive conveyance change between cross sections. When the Mapping Partner compiles elevation data photogrammetrically, the elevations shall be taken to the nearest 0.5 foot at the three most significant gradient breaks on each bank and at enough intermediate points to satisfy the following three criteria:

1. No adjacent points separated vertically by more than 20 percent of range;
2. No adjacent points separated horizontally by more than 5 percent of the complete channel cross section width; and
3. No adjacent points in the main channel separated by more than 10 percent of main channel width or 2 feet, whichever is greater.

Specified spacing is illustrated in Figure A-2. The assigned Mapping Partner shall read elevations and stations at each edge of water. The Zero Station (initial point) for each cross section must be the finally adopted terminus on the left bank (looking downstream). Stations must be the distance to the nearest foot measured along the straight, curved, or zigzag alignment of the cross section.

With automatic hydrologic and hydraulic analyses and LIDAR datasets, the cross sections established by the assigned Mapping Partner can be more numerous and represent shorter reaches. Because they can be easily "cut" from high-density datasets, multiple LIDAR cross sections enable the Mapping Partner to determine cross sections that are more truly representative of reaches.

For surveying cross sections beneath the water level, the method to be used depends on the depth and velocity of the stream. When water is shallow and can be waded, traditional differential leveling is used with conventional elevation rod (including rod extensions), using an attached bottom plate as necessary to prevent the rod from penetrating silt and mud. When water is deeper or too swift for wading, various hydrographic survey methods described in Chapter 8 of USACE Engineer Manual 1110-2-1003 (USACE, 1994) may be used. These may include small workboats with sounding poles or lead lines, or specialized hydrographic survey vessels with echo sounders, either single (vertical-beam) or multi-beam transducers.

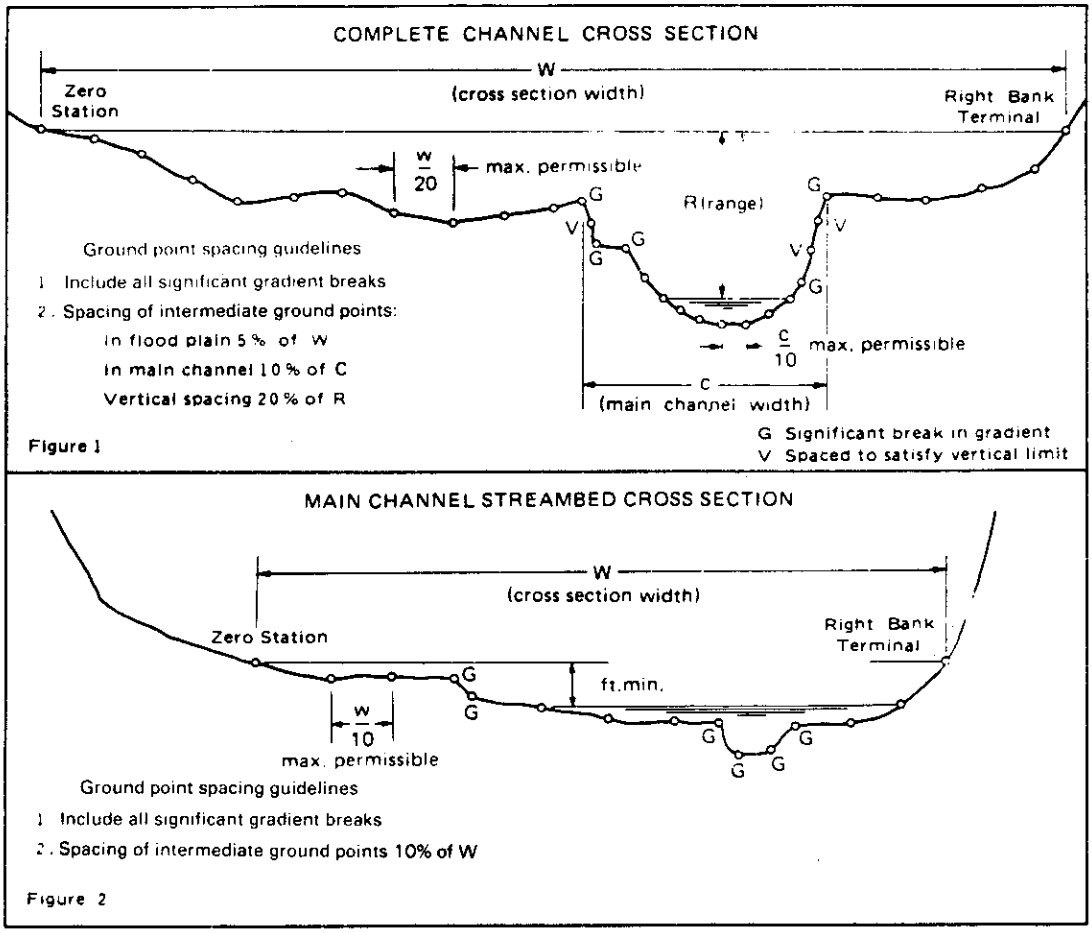

Figure A-2. Examples of Cross Section Ground Point Spacing

A.4.7 Hydraulic Structures **[February 2002]**

For detailed flood hazard analyses, the assigned Mapping Partner shall obtain the required dimensions and elevations of all hydraulic structures and underwater sections adjacent to the structures from available sources or by field survey where necessary. The Mapping Partner shall not establish dimensions and elevations of hydraulic structures by aerial survey methods (i.e., photogrammetry or LIDAR).

For bridges, sufficient data for input to modeling software usually includes the following:

- Size and shape of the opening;
- Upstream and downstream channel invert elevations;
- Entrance conditions (e.g., wingwalls, vertical abutments)
- Bridge deck thickness, low-steel elevation, and bridge parapet type (i.e., solid railing, open railing);
- Roadway embankment side-slope rate;
- Type and width of roadway pavement; and
- Top-of-road section for sufficient length for weir-flow calculations.

For culverts, sufficient data for input to modeling software or Federal Highway Administration culvert nomographs usually includes the following:

- Size and shape;
- Upstream and downstream channel invert elevations;
- Entrance conditions (i.e., headwall, wingwalls, mitered to slope, projecting);
- Roadway embankment side-slope rate;
- Type and width of roadway pavement; and
- Top-of-road section for sufficient length for weir-flow calculations.

For dams and weirs, sufficient data for input to modeling software usually includes the following:

- Top-of-dam elevation;
- Normal pool elevation;
- Principal spillway type, inlet and outlet elevations, and dimensions; and
- Emergency spillway (if applicable) type, elevation, and dimensions.

For approximate flood hazard analyses, the assigned Mapping Partner may estimate the bridge, culvert, dam, and weir data from photographs, orthophotos, or existing topographic mapping without performing field surveys.

A.4.8 Datums, Projections, Coordinate Systems, Coordinates [February 2002]

The horizontal and vertical datums, projection, and coordinate system for a Flood Map Project must be determined during the Project Scoping phase. Details are discussed in Appendices B and K of these Guidelines.

In addition to determining whether coordinates are to be in feet or meters, the assigned Mapping Partner must determine the number of decimal places to be used for x/y/z coordinates. Normally, feet are specified to two decimal places, and meters are specified to either two or three decimal places.

When dealing with decimal degrees, one arc degree equals approximately 367,000 feet. Therefore, decimal degrees to six decimal places would record latitude and longitude to the nearest 0.367 foot.

When dealing with degrees/minutes/seconds, one arc second equals approximately 102 feet. Therefore, seconds to two decimal places would record latitude and longitude to the nearest 1 foot.

A.4.9 Data Formats [April 2003]

The following digital file formats are acceptable with contours, breaklines, and other vector data, but additional software-specific formats may also be acceptable if preferred by Mapping Partners:

- DGN: MicroStation design file, internal proprietary drawing data base format;
- DO: Digital Line Graph (DLG) Optional file format for vector data (USGS);
- DWG: AutoCAD drawing file, internal proprietary drawing data base format;
- DXF: Drawing Exchange (Interchange) file, American Standard Code for Information Interchange (ASCII) or binary file format used to transfer data between CAD and GIS;
- E00: ARC/INFO Export (Interchange) file of either binary coverages or grids;
- MIF/MID: MapInfo data set, which contains vector drawings and tables (databases);
- SHP: ArcView Shape file, collection of files used in ArcView for vector drawings and database storage;
- SDTS: Spatial Data Transfer Standard, ASCII or binary file format designed to handle earth-referenced spatial data between dissimilar computer systems; and
- TAB: MapInfo native tabular format.

The following digital file formats are acceptable with mass points and TINs, but other software-specific formats may also be acceptable if preferred by Mapping Partners:

- ASCII x, y, z: Predominant character set encoding of computers;

- ASCII x, y, z with Attributes: Additional attributes such as acquisition dates, sensor make and model (when different sensors are used on a project), or LIDAR intensity values;
- BIN: Binary encoding of ASCII data; and
- TIN Arc/Info Export file format (other GIS software programs have similar formats).

The following digital file formats are acceptable with uniformly spaced DEMs, but other software-specific formats may also be acceptable if preferred by Mapping Partners:

- BIL: Band Interleaved by Line format, treats each line of pixels as separate units and then stores by lines;
- BIP: Band Interleaved by Pixel format, treats pixels as separate storage units
- BSQ: Band Sequential format, all data for a single band (in this case DEM) is written to one file;
- DEM: is a raster format used by USGS to record elevation data. Cell values reflect elevation data and not pixel brightness;
- ESRI Float Grid: 32 bit floating point raster grids for ESRI products;
- ESRI Integer Grid: 16 bit integer format;
- GeoTiff: Georeferenced Tagged Image File Format, one of the most widely supported file formats for storing bit-mapped images. Can be used with TWF (Tagged World File) for georeferencing; and
- RLE: Run Length Encoding, a band sequential format that stores the cell value and the number of times it occurs along a given raster line.

A.4.10 Hydrologically Enforced Elevation Data [February 2002]

It is normal for uniformly spaced DEM points to "jump" across a flooding source and fail to show that a flooding source passes through. Similarly, it is possible for irregularly spaced mass points (from LIDAR, for example) to fail to capture the lowest elevations of ditches and shorelines. Artificial "puddles" may then be created with no apparent outlet drain. When this occurs, breaklines are necessary to depict the true three-dimensional shape of the terrain, especially drainage features used for hydrologic and hydraulic modeling.

A hydro-enforced TIN uses drainage system breaklines to form triangle edges in the TIN data structure. A hydro-enforced DEM uses breaklines to lower selected DEM cells to enforce natural drainage in the Digital Terrain Model (DTM). The horizontal locations of these breaklines are determined from hydrographic vector data or from imagery. The z-values assigned to these breaklines start with the lowest elevation upstream from a "puddle" and slope downstream to an elevation where the natural drainage system resumes, as depicted by the TIN or DEM.

A similar situation occurs with bridges and culverts. Elevations on the tops of bridges and culverts will appear identical to a dam, so a hydraulic model would erroneously indicate that water cannot pass through these dams. Hydro-enforced TINs, DEMs, or contours ensure that top surfaces of bridges and culverts are cut by stream breaklines so that computer models will accurately represent drainage flow. Hydro-enforcement normally requires human intervention to "cut" breaklines so that TIN/DEM elevations and contours will correctly follow drainage patterns, rather than erroneously model the terrain to depict dams or puddles that do not actually exist.

A.4.11 Other Digital Topographic Data Requirements [April 2003]

Other requirements in the Digital Topographic Data Requirements Checklist (Table A-3), unique to LIDAR data, are documented in Section A.8.

Table A-3. Digital Topographic Data Requirements Checklist

Surface Description (choose one)
- ☐ Bare-earth surface (FEMA default)
- ☐ Top surface (e.g., treetops/rooftops)
- ☐ Bathymetric surface

Reflective surface (if using LIDAR)
- ☐ First ☐ Last (FEMA default) ☐ All
- ☐ LIDAR intensity returns
- ☐ Other simultaneous imagery

Vertical Accuracy (choose one)
- ☐ 1' contour equiv. ($Accuracy_z$ = 0.6 ft.)
- ☐ 2' contour equiv. ($Accuracy_z$ = 1.2 ft.)
- ☐ 4' contour equiv. ($Accuracy_z$ = 2.4 ft.)
- ☐ 5' contour equiv. ($Accuracy_z$ = 3.0 ft.)
- ☐ Other: $Accuracy_z$ = ___ ft.

Vertical accuracy at the 95% confidence level ($Accuracy_z$) = $RMSE_z$ x 1.9600 with normal distribution

Horizontal Accuracy (choose one)
- ☐ 1" = 500' equiv. ($Accuracy_r$ = 11' or 3.35 m)
- ☐ 1" = 1000' equiv. ($Accuracy_r$ = 22' or 6.7 m)
- ☐ $RMSE_r$ = 1 m
- ☐ $RMSE_r$ = _______

Horizontal accuracy at the 95% confidence level ($Accuracy_r$) = $RMSE_r$ x 1.7308

Data Model (choose one or more)
- ☐ Contours ☐ Mass points ☐ TIN (average point spacing = ___meters) *
- ☐ Cross sections ☐ Breaklines ☐ DEM (post spacing = ___meters)

* FEMA's standard DEM post spacing is 5-meters when mass points are supplemented with breaklines for hydraulic modeling. The TIN point spacing is typically smaller than the DEM post spacing to allow a denser network of irregularly-spaced points for interpolation of the uniformly-spaced DEM.

Horizontal Datum (choose one)
- ☐ NAD 27 ☐ NAD 83 (default)

Vertical Datum (choose one)
- ☐ NGVD 29 ☐ NAVD 88 (default)

Coordinate System (choose one)
- ☐ UTM ☐ State Plane ☐ Geographic

Units Note: For feet and meters, vertical (V) units may differ from horizontal (H) units
- ☐ Feet to ___ decimal places ☐ V ☐ H
- ☐ Meters to ___ decimal places ☐ V ☐ H
- ☐ Decimal degrees to ___ decimal places
- ☐ DDDMMSS to ___ decimal places

Feet are assumed to be U.S. Survey Feet unless specified to the contrary

Data Format (choose one or more)

Digital contour lines and breaklines
- ☐ .DGN
- ☐ .DO (DLG Optional)
- ☐ .DWG
- ☐ .DXF
- ☐ .E00
- ☐ .MIF/.MID
- ☐ .SHP
- ☐ SDTS
- ☐ TAB
- ☐ Other ___________

Mass points and TINs
- ☐ ASCII x/y/z
- ☐ ASCII with attribute data
- ☐ BIN
- ☐ TIN Arc/Info Export File
- ☐ Other ____________

DEMs
- ☐ ASCII x/y/z
- ☐ .BIL
- ☐ .BIP
- ☐ .BSQ
- ☐ .DEM (USGS standard)
- ☐ ESRI Float Grid
- ☐ ESRI Integer Grid
- ☐ GeoTiff
- ☐ .RLE
- ☐ Other ____________

File size or Tile size (choose one)
- ☐ File size ____ MB or 1 GB (max)
- ☐ Tile size _______ x ______ (specify feet or meters)
- ☐ Other tile size: ______________________________
- ☐ Buffer size: _________________________________

Other Quality Factors (optional, explain on separate page)
- ☐ Cleanness from artifacts
- ☐ Limits on size/location of void areas where there are no elevation data shown
- ☐ How elevations are to be shown for void areas
- ☐ Hydro-enforcement — Bridges/culverts removed? ☐ Yes ☐ No
- ☐ Other requirements

A.5 Ground Control **[February 2002]**

Ground control is used to control the network accuracy of derived ground and aerial surveys so that data are correctly registered to the horizontal and vertical datums. When properly controlled, DFIRM work maps (including topographic data, cross sections, and hydraulic structure surveys) will accurately register to DOQs or other DFIRM base maps that are similarly registered to our National horizontal and vertical datums in compliance with applicable FGDC standards.

Elevation Reference Marks (ERMs), used by FEMA in the past, are not suitable for NFIP ground control as defined herein because ERMs lack both the minimum accuracy and stability needed for three-dimensional ground control points. ERMs are suitable only for Temporary Bench Marks (TBMs) established during the performance of a Flood Map Project, and the assigned Mapping Partner shall provide documentation for the TBMs in the Technical Support Data Notebook. ERMs must not be shown on DFIRMs. The only ground control points printed on DFIRMs are those that are included in the NSRS.

A.5.1 National Spatial Reference System **[February 2002]**

Aerial mapping and surveying projects, and products derived therefrom, must be connected to NSRS monuments. Mapping Partners can search the NSRS database by accessing the National Geodetic Survey (NGS) home page at www.ngs.noaa.gov, selecting the “Data Sheets” option, and retrieving NGS data sheets by using either the "Rectangular Search" or "Radial Search" option. With the “Rectangular Search” option, the user must define the minimum and maximum values for the latitudes and longitudes that bound the area of interest. For the “Radial Search” option, the user must specify the search radius and latitude/longitude for a point near the center of the area of interest, or at selected points elsewhere. From all available NGS Data Sheets, users can select data sheets from the following options:

- Any Horz. And/or Vert. Control;
- GPS Sites Only;
- Any Horizontal Control;
- Horizontal Order-A;
- Horizontal Order-B or Better (HARN);
- Horizontal Order-1 or Better;
- Horizontal Order-2 or Better;
- Any Vertical Control;
- Vertical Order-1;
- Vertical Order-2 or Better;
- FBN and/or CBN; or

- PAC and/or SAC.

"HARN" stands for High Accuracy Reference Network, and some HARNs have high horizontal accuracy only. "FBN" stands for the Federal Base Network of control monuments. "CBN" stands for the Cooperative Base Network, established by States, counties and/or municipalities. "PAC" stands for Primary Airport Control stations. "SAC" stands for Secondary Airport Control stations.

The "GPS Sites Only" option provides three-dimensional control points that have been surveyed using GPS and that have "network accuracy" relative to the national geodetic datum. These control points have "Ellipsoid Order" specified on the NGS Data Sheets. The "Any Horz. And/or Vert. Control" option provides conventional horizontal control points and vertical benchmarks, as well as GPS control points. If these control points and bench marks do not specify Ellipsoid Order, they have "local accuracy" relative to the coordinates of other directly connected, adjacent control points, but have not yet been surveyed using GPS relative to the national geodetic datum. Such local control points can be connected to the NSRS, to determine their "network accuracy," by 2 to 3 days of GPS surveys (in accordance with NGS-58 procedures for Secondary or Primary Base surveys) relative to NSRS monument(s) for which Ellipsoid Order has been specified.

If the rectangular or radial search area is so large that more than 100 NSRS monuments are identified within the defined area, the user will receive an error message. The error message will specify that the rectangular area must be subdivided, or the radius of the circular search area must be reduced, so that there will be fewer than 100 NSRS monuments within the specified area.

GPS is the preferred method for extending any survey control from NSRS monuments to other control points and benchmarks so that all control used for a Flood Map Project will have network accuracy relative to the NSRS and the horizontal and vertical datums used.

A.5.2 Horizontal Control **[February 2002]**

At a minimum, all horizontal control must be to an accuracy level of NGS Second Order or better. This horizontal accuracy is easily achievable when NGS-58 5-centimeter local network accuracy procedures are used and when NSRS monuments are used for GPS base stations.

A.5.3 Vertical Control **[February 2002]**

The assigned Mapping Partner must perform necessary field surveys to maintain vertical control, with all elevations referenced to the National Geodetic Vertical Datum of 1929 (NGVD29) or to the North American Vertical Datum of 1988 (NAVD88). The vertical datum may be either NGVD29 or NAVD88, but not mixed within a single Flood Map Project. FEMA recommends that all new Flood Map Projects be referenced to NAVD88. See Appendix B of these Guidelines for additional information on the use of NGVD29 and NAVD88. During the Project Scoping phase of a Flood Map Project, the Mapping Partner must clarify whether to use NGVD29 or NAVD88 before beginning any survey work.

For vertical control surveys, the assigned Mapping Partner must use 5-centimeter or better GPS procedures (as specified in NGS-58 for local network accuracy) or Third-Order (or better) differential leveling, or trigonometric leveling for short distances. The Mapping Partner shall establish vertical control points, for leveling of photogrammetric stereo models, with elevations accurate to within 5 centimeters, relative to the NSRS bench marks of Second-Order or higher accuracy used for the survey. For county-size and smaller areas, GPS is preferred for establishing vertical control points if the Mapping Partner uses precise Differential GPS (DGPS) techniques, with the base station receiver simultaneously measuring the elevation of a local NSRS bench mark of Second-Order or higher accuracy.

NGS has published a national geoid model and PC-based computer software called GEOID99 that converts from ellipsoid heights (derived from GPS) to orthometric heights (derived from precise leveling) nationwide with a standard deviation of 1 centimeter for points spaced 10 kilometers apart. When the assigned Mapping Partner uses DGPS techniques within a single county, this correction for variable height of the geoid above the ellipsoid in non-mountainous areas is insignificant. NGS designed GEOID99 to be used with elevations referenced to NAVD88, not NGVD29. NGS has also published another PC-based software program, called VERTCON, which converts elevations referenced to NGVD29 to NAVD 88 for any horizontal coordinate pair entered (longitude/latitude or easting/northing). Both GEOID99 and VERTCON programs may be downloaded from the NGS portion of the NOAA Web site at www.ngs.noaa.gov.

A.6 Ground Surveys [February 2002]

Monuments selected for DGPS base stations for all surveys listed in this section will have the best available Horizontal Order, Vertical Order, and/or Ellipsoid Order, and Stability C or better. Where possible, these monuments must be the same NSRS monuments used for airborne GPS control of mapping aircraft for photogrammetric or LIDAR surveys. This eliminates the possibility that discrepancies may be caused by inconsistencies between different control points.

A.6.1 Photogrammetric Control Surveys [February 2002]

Primary photogrammetric control will consist of a network of control points adequate to produce maps with a 4-foot (rolling/hilly terrain) or 2-foot (flat terrain) contour interval. The assigned Mapping Partner shall include enough points in the primary network so that no stereomodel ground-surveyed control point (picture point) is farther than 15,000 feet from the nearest primary control point in that network. The Mapping Partner shall use sufficient points to produce a stable aerotriangulation solution.

Points must be located in areas where they can be read from as many stereomodels as possible, except in cases where the point lies within 0.33 inch of the edge of the stereomodel. The assigned Mapping Partner shall ensure that no more than two stereomodels are without vertical control points unless direct georeferencing is used (See Subsection A.7.3). The Mapping Partner shall locate and number the points on the image side of the contact print and shall number and describe the points on the reverse side. To ensure sufficient and accurate selection, points must be selected under the supervision of an ASPRS-certified photogrammetrist.

A.6.2 Cross-Section Surveys [February 2002]

The assigned Mapping Partner must "anchor" terminal ends of cross sections by GPS surveys relative to NSRS monuments having both Ellipsoid Order and Vertical Order specified on the NGS data sheets. The Mapping Partner may use traditional traverse/trigonometric leveling procedures between the terminal points to determine x/y/z coordinates of points that represent significant breaks in ground slope and at changes in the hydraulic characteristics of the floodplain. Each cross section must cross the entire 0.2-percent-annual-chance floodplain. The Mapping Partner shall determine elevations at each edge of water and shall determine invert elevations at the deepest part of the stream. The Mapping Partner shall perform underwater surveys in accordance with the requirements in Subsection A.4.6.

A.6.3 Hydraulic Structure Surveys [February 2002]

For bridges and culverts, survey information to support hydraulic modeling includes the following:

- Size and shape of bridge/culvert openings;
- Upstream and downstream channel invert elevations;

- Entrance conditions (vertical abutments, headwalls, wingwalls, mitered to slope, projecting);
- Bridge deck thickness, low steel elevation, and bridge parapet type (i.e., solid, open railing);
- Roadway embankment side-slope rate;
- Type and width of roadway pavement; and
- Top-of-road section for sufficient length for weir-flow calculations

For dams and weirs, survey information to support hydraulic modeling includes the following:

- Top-of-dam elevation;
- Normal pool elevation;
- Principal spillway type;
- Inlet and outlet elevations and dimensions; and
- Emergency spillway type, elevation and dimensions.

A.6.4 Checkpoint Surveys **[February 2002]**

The assigned Mapping Partner shall perform checkpoint surveys to establish independent QA/QC checks for points of higher accuracy than the geospatial datasets being evaluated. The Mapping Partner shall use the checkpoints to check the horizontal accuracy of base maps or the vertical accuracy of digital elevation data. Checkpoints are most commonly used to determine the vertical accuracy of LIDAR datasets. The Mapping Partner shall perform checkpoint surveys to achieve 5-centimeter Local Network accuracy per NGS-58. The Mapping Partner shall select checkpoint locations on Government-owned or public areas, where possible, to avoid the need for obtaining individual landowner permission.

Checkpoints are normally surveyed with transections or small clusters of points, at least two of which have been surveyed using GPS relative to NSRS monuments that have both Ellipsoid Order and Vertical Order specified on their NGS data sheets. If selected monuments are farther than 20 kilometers (36 miles) from the test areas to be surveyed, the assigned Mapping Partner shall establish Secondary Base Stations so that final surveys of checkpoints satisfy NGS-58 requirements for Local Network accuracy of 5-centimeters at the 95-percent confidence level.

Alternatively, the assigned Mapping Partner may use GPS real-time-kinematic (RTK) procedures provided the following conditions are met:

1. The base station is an existing NGS three-dimensional mark or a new NGS-58 mark,
2. RTK procedures are used only in open areas and each RTK point is occupied twice with at least 2 hours' difference in time between observations, and

3. The difference between observations does not exceed 5 centimeters.

The assigned Mapping Partner may use third-order conventional surveys to extend control from GPS "anchor points" to other transection or cluster points, especially when checkpoints are in forested areas where GPS signals are blocked.

When checkpoints are to be used for QA/QC reviews of digital elevation data (e.g., TINs, DEMs), the checkpoints must be at least 5 meters away from any breakline where there is a change in slope. Such checkpoints must be on flat or uniformly sloping terrain. The assigned Mapping Partner shall take photographs to record the location of the checkpoint relative to its surroundings, and to verify the vegetation category within which the checkpoint is located. The Mapping Partner shall mark each checkpoint with a 60d nail or larger. The Mapping Partner shall write the station ID number on an adjacent above-ground stake within 1 foot of the referenced stake, to aid in subsequent recovery if required during the course of the Flood Map Project. The Mapping Partner shall use "to reach" location descriptions and photographs to document the location, the land cover surrounding each stake, and the uniform slope of the terrain surrounding each stake.

A.6.5 Survey Records **[February 2002]**

Upon completion of the project, the assigned Mapping Partner shall deliver information meeting the requirements described below, upon request, to the FEMA Lead.

- Field notebooks must be carefully and neatly prepared, identified, indexed, and preserved.
- All data regarding the establishment and extension of vertical and horizontal control, including descriptions of all established and recovered monuments, must be recorded.
- Each field notebooks must contain the name and the field address/location of the Party Chief, and the identity of the survey instruments.
- Each field notebook must be numbered and marked with a brief description of the contents on the cover, carefully indexed, and each page numbered.
- For conventional surveys, each horizontal traverse line and vertical control line must be identified by number and brief description in the field book.
- The first page used on each day of fieldwork must be dated.
- Each field notebook must be free of erasures; any line of horizontal and vertical control may be rejected by the FEMA Lead if any erasure is made in recording the data for that line.
- If the field notes are electronically recorded, printouts of the electronically recorded field notes must be provided.
- For GPS surveys, the full network adjustment report must be provided.

The assigned Mapping Partner shall furnish a schematic control diagram of the survey records on a photo index for all basic horizontal and vertical control pertinent to the project. The schematic diagram must show all existing and established control points properly identified in their approximate location. The schematic diagram also must show all traverse lines with their designations to include the beginning and ending points.

A.7 Photogrammetric Surveys [February 2002]

The aerial photogrammetric surveys that a Mapping Partner may perform generally will include establishment of the following:

- Photogrammetrically obtained stream and valley cross sections (portions above water);
- Planimetric compilation manuscript of key hydraulic structures (bridges, culverts, dams, levees);
- For rolling/hilly terrain, 4-foot contours of floodplains from the waterline to the nearest 4-foot contour above the 0.2-percent annual chance flood elevation line; for flat terrain, 2-foot contours of floodplains from the waterline to the nearest 2-foot contour above the 0.2-percent-annual-chance flood elevation line;
- Contours of 1-percent-annual-chance and 0.2-percent-annual-chance floodplain elevations (if profiles have been determined from previous studies); and
- Tabulations of spot heights on hydraulic structures and TBMs.

A.7.1 Aerial Photography [February 2002]

The assigned Mapping Partner shall first determine the area to be flown, the approximate location and vertical ranges of the cross-sectional information to be flown, and the approximate location and vertical ranges of the cross-sectional information needed to represent all reaches under study. In planning for photogrammetry, the Mapping Partner shall perform an approximate analysis to estimate the 1- and 0.2-percent-annual-chance flood elevations for every reach for which a detailed flood hazard analysis is required in order to estimate the extent of horizontal aerial photo coverage required. Where available, the Mapping Partner may use FIRMs, USGS Floodprone Area Maps, or similar studies for this purpose. The area of detailed study, for which stereophotography is required, normally includes a 1,000-foot buffer zone outside the 0.2-percent-annual-chance flood limits (see Figure A-1).

Schedule requirements are an important consideration in the decision regarding the applicability of aerial photogrammetry. In many areas, good aerial photography can be obtained only during short periods of the year, when foliage does not obscure the landscape, the ground is free of snow, and the sky is clear. Poor weather and difficult terrain conditions also can delay required ground surveys. However, these factors have no effect on the schedule for determination of cross sections and contours by photogrammetry once photography and ground control have been completed. The Project Team shall ensure that the schedule for the Flood Map Project reflects these considerations to avoid delays.

Aerial photography shall be flown under the following conditions:

- While the sun angle is above 30 degrees;
- When there is no snow cover;

- When the flooding sources are in the main channels; and
- When leaves are off the trees.

The assigned Mapping Partner shall perform aerial surveys under the direct supervision of a Registered Land Surveyor or ASPRS-Certified Photogrammetrist, consistent with State regulations.

The aerial photography deliverables consist of the following:

- One photo index of all photography on a sheet that is no larger than 24 inches x 36 inches;
- One set of black-and-white contact prints of photographs on resin-coated, neutral-toned, medium-weight paper with matte surface; and
- Two sets of black-and-white prints of alternate photographs enlarged two times on resin-coated, neutral-toned, medium-weight paper with matte surface (optional if requested).

All deliverables must provide complete single coverage of the flight area. The screen must be appropriate so that quality bluelines of a pilot sheet can be made and accepted prior to quantity production.

A.7.2 Aerial Triangulation **[February 2002]**

The assigned Mapping Partner normally shall use Fully Analytical Aerial Triangulation (FAAT) of the entire floodplain area and buffer zone for which stereo coverage is required. No analog or semi-analytical aerial triangulation procedures are to be used. The positional accuracy of horizontal and vertical photo control established by FAAT must meet or exceed each of the following conditions:

- The horizontal RMSE of the final block adjustment must not exceed 1/10,000 of the flight height.
- The vertical RMSE of the final block adjustment must not exceed 1/9,000 of the flight height.
- The maximum allowable error of any vertical or horizontal point must not exceed 3 RMSE.
- The mean of all points (taking into account positive and negative signs) must not exceed 1/15,000 of the flight height.

Upon completion of all aerial triangulation work, the assigned Mapping Partner shall prepare an aerial triangulation report for submission to the FEMA Lead. The report shall include, but not necessarily be limited to the following:

- Flight lines;
- Exposure stations or model layout; and

- Control points appropriately labeled with station designations, computer designations (if any), and agency responsible for establishing the stations.

Aerial triangulation results shall include the following:

- All residuals (misclosures) at ground control points with and without use of checkpoints;
- Computer printout of the final adjusted aerial triangulation solution to horizontal and vertical ground control, including the final State Plane and/or UTM coordinates for all ground control points, pass points, and check points;
- Identification of all points included in the initial solution that were subsequently discarded, with an explanation of the reasons for being discarded;
- Identification of the weighting factors applied to all points used in the final solution;
- Diskette containing the coordinate data in ASCII format; and
- A brief narrative explaining the above solutions as well as descriptions of equipment, procedures, and computer programs used.

The report also is to include RMS error summaries for bundle adjustment photographic measurement residuals or strip tie point residuals and misclosures at control/check points. In addition, the report must describe significant misfits encountered at control points, and steps taken to analyze such misfits and to rectify the discrepancies.

A.7.3 Direct Georeferencing **[February 2002]**

A primary purpose of aerial triangulation is to use ground control points, pass points, and tie points in a FAAT least squares block adjustment to determine the position and orientation of the mapping camera at the instant of each film exposure. The *position* consists of the x/y/z coordinates of the camera's focal point in the air, and the *orientation* is the angular roll (ω), pitch (φ), and yaw (κ) of the camera about the x, y and z axes. Collectively, these six position and orientation terms (x, y, z, ω, φ, κ) are called the "exterior orientation (EO) parameters" of each photograph. These EO parameters for each photograph are needed to correctly establish the stereomodel needed to prepare accurate three-dimensional mapping from two-dimensional photographs.

"Direct Georeferencing" is the direct measurement of the position and orientation parameters of a remote sensor. The state-of-the-art technology in Direct Georeferencing is the GPS-aided inertial navigation system (INS). The INS consists of an inertial measurement unit (IMU) and a navigation processor (NP). The IMU comprises three accelerometers, three gyroscopes, and the electronics to provide digitally encoded samples of the accelerometer and gyro data on a serial interface to measure the specific force vector experienced by the IMU. The force vector is the vector sum of the local gravity vector and the acceleration vector experienced by the IMU. The NP solves Newton's equations of motion of the IMU on the rotating earth, and establishes the local North, East, and Down directions.

The INS essentially provides direct measurements of the ω, φ, and κ EO parameters. A GPS-aided INS uses a Kalman filter to regulate the INS position and velocity errors to be consistent with GPS position and velocity errors, regulating the INS angular errors and continuously improving the INS alignment The net result is that GPS-aided INS provides direct recording of the six EO parameters for each photograph, providing Direct Georeferencing of those photographs without the normal FAAT solution.

It is becoming common practice with direct georeferencing solutions to use only a few ground control points, at the outer perimeter of a mapping project area, in conjunction with GPS-aided INS data to perform a complete aerial triangulation, without the need for hundreds of surveyed ground control points. Although Direct Georeferencing is an acceptable alternative to FAAT, it is a new technology that is more commonly used in inaccessible or sensitive terrain (e.g., wetlands) where there is additional reason to avoid the survey of numerous ground control points. Technically, with Direct Georeferencing solutions, no ground control points are needed; however, a few are advisable for overall quality control of the mapping project.

A.7.4 Photogrammetric Compilation [February 2002]

Photogrammetric compilation for a Flood Map Project normally must include determination of floodplain cross-section geometry; compilation of 4-foot (or 2-foot) contours in the floodplain; and preparation of limited planimetric map features for registration to digital orthophoto base maps, for example. The compilation of such FIRM work map information requires high-precision photogrammetric equipment, hardware/software, and experienced operators.

A.7.4.1 Cross Sections [February 2002]

On the enlarged photographs, the assigned Mapping Partner shall designate the position, approximate termini, and minimum range in elevation for each cross section to be read, and the position of approximately two photo-identifiable ground points near each cross section. The range in elevation is the vertical distance from the water surface at the time of photography to the upper limit of the cross section. If the channel is dry, the lowest point in the streambed is used to define the range.

The assigned Mapping Partner shall compile cross sections in accordance with requirements specified in Subsection A.4.6.

A.7.4.2 Contours [February 2002]

The assigned Mapping Partner shall compile contours of the areas within the estimated 0.2-percent-annual-chance floodplain and buffer zone. The Mapping Partner may use DEMs with uniformly spaced elevation points, non-uniformly spaced mass points and breaklines, and TINs to generate contours so long as the resulting contours satisfy the specified vertical accuracy requirements. The Mapping Partner shall start the contours at the next even-foot elevation above the water surface and continue at 4-foot intervals (2-foot intervals for flat terrain) until the shaded area edge is reached. The specified format is illustrated in Figure A-3.

In the compilation manuscript, the assigned Mapping Partner shall include 4-foot contour lines (2-foot contour lines for flat terrain) on each bank of each flooding source for which cross sections are read. The Mapping Partner shall use the contours to delineate floodplain boundaries between cross sections after precise flood elevations are computed.

In situations where the 1- and 0.2-percent-annual-chance flood elevations are available, or can be closely approximated in advance of the photogrammetric compilation, the assigned Mapping Partner shall consider the use of "bracketing contours" that cover only the ranges of elevations near those of the floods for which floodplain boundaries are to be delineated on the work maps. Compilation costs can often be reduced in this manner by eliminating the plotting of contours above or below the expected range of these floods. The Mapping Partner shall obtain approval from the FEMA Lead before using this approach.

A.7.4.3 Planimetric Work Maps [February 2002]

The assigned Mapping Partner shall compile a work map, compiled on different GIS layers, that shows the following:

- Alignment of all cross sections read, with zero stations plotted and labeled;
- Low water outlines of streams;
- Limited planimetric features of hydraulic structures, e.g., bridges, culverts, dams, dikes and levees; and
- Any contours that are specified.

Streets, highways, and railroads are not required because they should be visible on community-provided or DOQ base maps.

Work map specifications are provided in Volume 1, Subsection 1.4.2.3 of these Guidelines. Digital data submittal requirements are provided in Appendix L of these Guidelines.

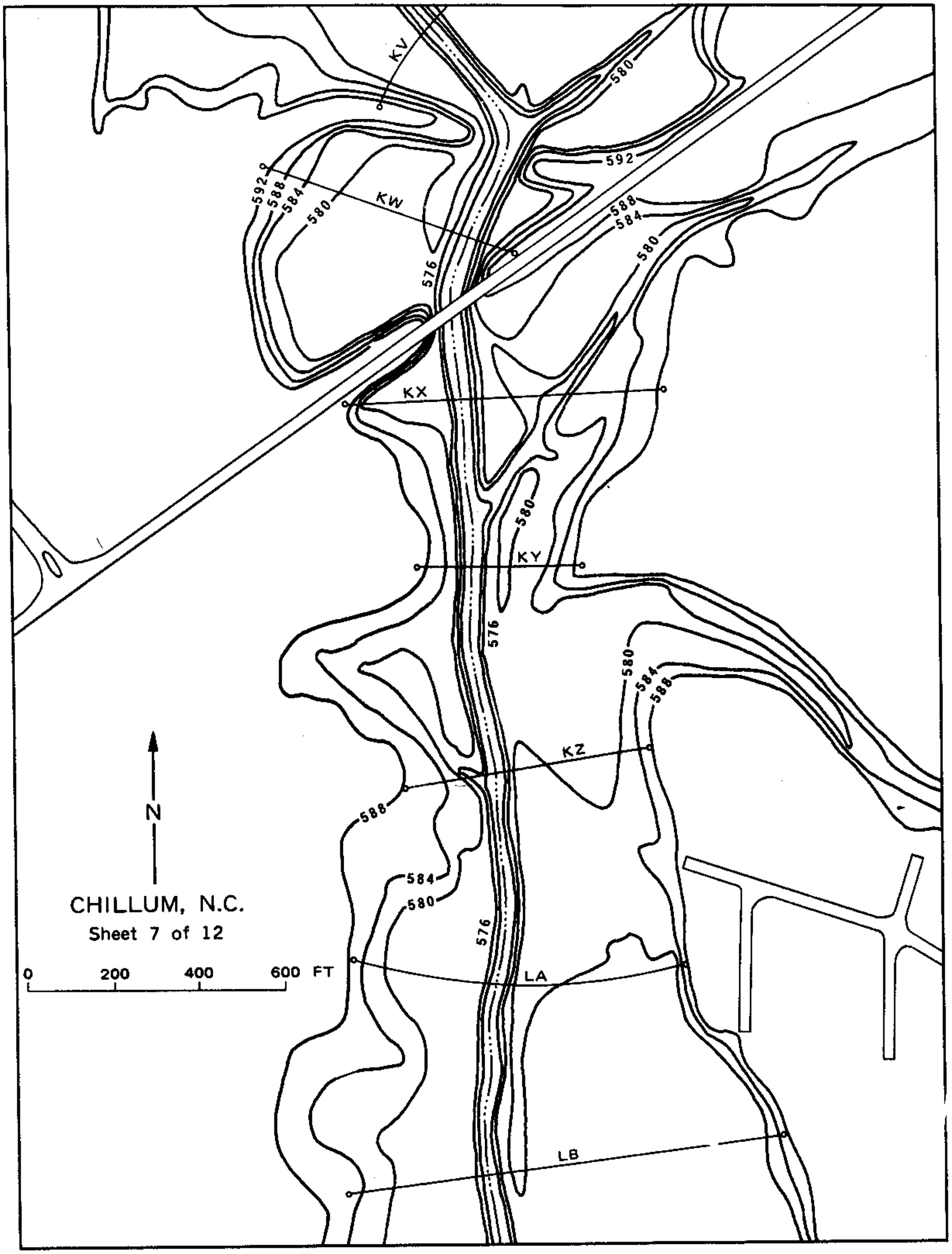

Figure A-3. Example Floodplain Contours

A.7.5 Quality Control and Quality Assurance [February 2002]

FEMA uses qualifications-based criteria for selection of contracted photogrammetric Mapping Partners, recognizing that quality work maps result from professional Mapping Partners with superior engrained QA/QC review procedures. Overall QA/QC is the responsibility of the assigned Mapping Partner and is exercised at specific stages of the map production process. FEMA's role during data acquisition and map/data base compilation generally must be limited to performing QA/QC reviews, which may involve only cursory spot-checking of the work maps and supporting data, or to performing formal field map testing using FEMA or third-party forces. This philosophy is especially true for photogrammetric mapping which is a mature technology and for which procedures have been well established for many decades

The QA/QC process for photomapping work may be divided into two categories: process QC and product QA.

A.7.5.1 Process Quality Control [February 2002]

Process QC is primarily the responsibility of the assigned Mapping Partner. This includes QC reviews of flight alignments, photographic quality, aerial triangulation, stereocompilation, and completeness of supporting data (e.g., cross sections, profiles). The degree of process QC required will be governed by the contract specifications.

A.7.5.2 Product Quality Assurance [February 2002]

Product quality will be assured by FEMA using a variety of inspection and testing techniques on the final deliverables. FEMA may perform the product QA reviews or they may task other Mapping Partners to perform the QA reviews. Product QA checks, tests, or field inspections likely will be called for in the Statement of Work or Mapping Activity Statement for each Flood Map Project; however, FEMA has the option to waive any or all tests and accept the delivered product without formal field testing/checking.

The assigned Mapping Partner shall be responsible for internal QC functions involved with field surveying, photography and laboratory processing, aerial triangulation, stereocompilation and field checking and editing of the photogrammetrically made measurements and compiled maps to ascertain their completeness and accuracy. Also, the Mapping Partner shall make the additions and corrections that are required to complete the work maps, cross sections, and Flood Profiles.

A.7.5.3 Quality Assurance of Digital Elevation Models and/or Triangulated Irregular Networks [February 2002]

Detailed QA/QC procedures for DEMs and/or TINs produced from LIDAR, photogrammetry, or other source are provided in Subsection A.8.6.

A.7.5.4 Quality Assurance of Contours [February 2002]

The assigned Mapping Partner must test the accuracy of contouring on work maps by comparing a photogrammetrically derived cross section on the work map with a cross section established by ground survey. The FEMA Lead shall designate the location of each test traverse. The Mapping Partner shall record the elevation and station for each break in the terrain and for each contour elevation. Ground-surveyed cross sections must be at least 6 inches long at final map scale, with an elevation measured at least every 100 feet on the ground, and must cross at least 10 contour lines when possible. Cross sections must start and close on map features or previously established control points. In flat areas and at principal road and railroad intersections, spot elevations may be checked. In general, one cross section per map sheet is sufficient.

A.7.5.5 Acceptance/Rejection [February 2002]

FEMA will accept a Flood Map Project when FEMA or a Mapping Partner designated by FEMA has performed sufficient testing to ensure that each phase of the mapping meets FEMA standards and specifications. When a series of work maps are involved, the existence of errors (i.e., map test failure) on any individual sheet will constitute prima facie evidence of deficiencies throughout the project (i.e., all other sheets are assumed to have similar deficiencies); and field map testing will cease.

When the first ground-surveyed test cross section indicates that a work map fails to comply with accuracy requirements, FEMA or an assigned Mapping Partner shall make an additional test cross section. This cross section generally shall be parallel to the first cross section at a distance from the first as specified by FEMA. No work map is to be rejected unless the sum of the lengths of the test cross sections completed is 12 inches or more at final map scale. To determine acceptability of the contouring, the data from all the cross sections are combined and treated as a unit.

A.8 Airborne Light Detection and Ranging (LIDAR) Surveys [February 2002]

When Mapping Partners choose to use airborne LIDAR systems for gathering the data necessary to create digital elevation data for hydraulic modeling of floodplains, digital terrain maps, and other NFIP products, the guidelines and specifications presented herein must be used.

LIDAR systems may not be able to gather all of the data necessary to create those products. Data in areas such as bodies of water or dense forests may not meet the requirements of this Appendix. For FEMA products containing such areas, the assigned Mapping Partner shall supplement LIDAR data with data acquired by other means, as needed for hydraulic modeling. Lesser standards may be applied for hydrologic modeling of watersheds or other studies.

A.8.1 System Definitions [February 2002]

For the purpose of these Guidelines, LIDAR is defined as an airborne laser system, flown aboard rotary or fixed-wing aircraft, that is used to acquire x, y, and z coordinates of terrain and terrain features that are both manmade and naturally occurring. LIDAR systems consist of an airborne GPS with attendant GPS base stations, Inertial Measurement Unit (IMU), and light-emitting scanning laser.

The system measures ranges from the scanning laser to terrain surfaces within a scan width beneath the aircraft. The time it takes for the emitted light (LIDAR return) to reach the earth's surface and reflect back to the onboard LIDAR detector is measured to determine the range to the ground. Scan widths will vary, depending on mission purpose, weather conditions, desired point density and spacing, and other factors.

The other two components of LIDAR systems are the airborne GPS, which ascertains the in-flight three-dimensional position of the sensor, and the IMU, which delivers precise information about the attitude of the sensor, i.e., the roll, pitch and heading.

A.8.2 General Guidelines for Use [February 2002]

Two important factors in the LIDAR system mission planning are the point density of the randomly spaced LIDAR points and the point spacing of the uniformly spaced DEM points derived from the randomly spaced LIDAR returns. The point density necessary to accurately represent terrain and terrain features will depend on flight conditions, mission purpose, and required accuracy. As discussed in Sections A.3 and A.4, DEM point spacing of 5 meters or less and vertical accuracy of 1.2 feet at the 95-percecent confidence level ($Accuracy_z$) is required for digital elevation data equivalent to 2-foot contours for flat terrain, and $Accuracy_z$ of 2.4 feet is required for digital elevation data equivalent to 4-foot contours for rolling to hilly terrain.

Flight-path planning is another important factor in the LIDAR system mission. The flight path shall cover the study area satisfactorily including both parallel flight lines and enough cross flight lines to eliminate shadowing and allow for proper quality control.

Unlike aerial photogrammetry, LIDAR missions can be flown without regard to sun angle. Flights may take place at night, if conditions otherwise allow. However, it is recommended that some form of imagery exist over the LIDAR area. Simultaneous video or digital imagery cannot be acquired if LIDAR data are acquired at night, but LIDAR intensity returns can be acquired day or night, and these help to identify features during LIDAR post-processing. Alternatively, digital orthophotos acquired at a different time can be used for this purpose.

Mapping Partners shall obtain elevation and measurement information related to subsurface channel and hydraulic structure geometry through the use of other mapping technologies over deep or turbid water. In some instances, Mapping Partners can accomplish shallow water and near-shore coastal surveys using airborne LIDAR bathymetric systems equipped with lasers operating in portions of the light spectrum that allow transmission through water.

LIDAR system tolerance for inclement weather conditions (e.g., high winds, wet snow, rain, fog, high humidity, low cloud cover) generally is higher than that of photogrammetric methods. However, such conditions have been known to degrade the accuracy of laser return data. Therefore, Mapping Partners shall generally avoid missions during inclement weather.

High point densities may allow satisfactory data collection in areas of dense foliage. Still, care shall be taken in planning missions with regard to both natural (vegetative) and manmade (structure) ground cover. Pulse width, beam divergence, first and last pulse return discrimination, and choice of the post-processing algorithms used for vegetation or structure removal may all affect the accuracy of LIDAR-derived data in areas of dense foliage.

A.8.3 Performance Standards **[February 2002]**

The accuracy standards in Sections A.3 and A.4 also shall apply to NFIP maps and map products derived from LIDAR systems. LIDAR-derived data shall have the accuracy required to produce topographic maps and products that meet NSSDA.

FEMA is not aware of any existing LIDAR system performance standards. Current information about LIDAR systems is available from ASPRS (See ASPRS, 2001), National Oceanic and Atmospheric Administration (NOAA), National Aeronautic and Space Administration, USACE, LIDAR system manufacturers and venders, and private firms that provide LIDAR system services. As professional or trade associations issue specifications and standards, FEMA may adopt those standards and specifications and amend this Appendix.

A.8.3.1 Overall Standards **[April 2003]**

The assigned Mapping Partner shall furnish all necessary materials and equipment. The Mapping Partner also shall supply the supervisory, professional, and technical services personnel required to manage, survey, document, and process all data associated with LIDAR system mapping, scanning, and digital image processing. The Mapping Partner shall provide all deliverables in accordance with the SOW, MAS, or other contract or other agreement with FEMA and the requirements in this Appendix.

DEM posting shall be the minimum allowed by the data and shall not exceed 5 meters. As specified in Section A.3, $Accuracy_z$ shall normally be 1.2 foot (equivalent to 2-foot contours) in flat terrain and 2.4 feet (equivalent to 4-foot contours) in rolling to hilly terrain.

The Mapping Partner shall define which ellipsoid model and geoid model were used to obtain orthometric heights. Geoid models are produced and published by NGS and are updated nominally every three years. The latest NGS geoid model shall be used. It is important to document what geoid model was used in order to refine the orthometric heights as newer geoid models are published by NGS.

Data Voids

For the purposes of this Appendix, *data voids* are areas not within two times the DEM posting of data points. Data voids may occur from several different causes, including the following:

- LIDAR pulses may be naturally absorbed by water bodies or areas recently covered with asphalt. Such voids are normally considered to be unavoidable.
- The LIDAR system may have malfunctioned for some reason.
- Heavy winds, flight navigation system error or pilot error may have caused "holidays" between flight lines.
- Data points may be intentionally removed as part of the bare-earth post-processing to delete points that impinged on the tops of manmade structures or failed to penetrate dense vegetation.

Data voids caused by system malfunctions or flight line holidays are unacceptable, requiring new flights. Data voids caused by removal of LIDAR data points on manmade structures are always acceptable. Data voids caused by removal of LIDAR data points on dense vegetation are subject to additional guidelines, depending on whether or not the voids exist inside or outside the floodplain for which hydraulic modeling is to be performed.

When data voids exist outside the floodplain, hydrologic modeling of the watershed can still be performed acceptably by "filling" the voids through interpolation from surrounding points.

When data voids exist inside the floodplain, the cause, size, and location of the voids all have a bearing on whether additional ground surveys will be required to "fill" the voids. For example, if the data voids are caused by dense mangrove or sawgrass areas, supplemental ground surveys within such areas are not needed. These voids are normally "filled" by interpolation from elevation points immediately surrounding the mangrove or sawgrass areas. When small data voids of less than 1 acre are caused by removal of points in other types of dense vegetation, the assigned Mapping Partner may employ similar interpolation procedures at the discretion of the FEMA Lead.

The principal scenario where additional ground surveys are required involves larger void areas, normally larger than 1 acre, located in areas where representative cross sections must be cut. If equally acceptable areas exist elsewhere to cut representative cross sections, the FEMA Lead may decide that the additional expense is unwarranted for filling larger data voids by ground surveys. This judgment call is roughly equivalent to photogrammetric mapping where the photogrammetrist cannot see through the dense vegetation, determines areas to be "obscured," and maps the contours with dashed lines. In such cases, the photogrammetrist compiles representative cross sections only where the bare earth terrain can be seen in stereo, and performs ground surveys of additional cross sections only if alternative photogrammetrically compiled locations for cross sections are determined to be unacceptable.

Artifacts

Artifacts are regions of anomalous elevations or oscillations and ripples within the DEM data resulting from systematic errors, environmental conditions, or incomplete post-processing. They may result from malfunctioning sensors, poorly calibrated instrumentation, adverse atmospheric conditions, or processing errors. When artifacts are not totally removed, the assigned Mapping Partner shall provide an analysis of the effects of the remaining artifacts on DEM accuracy. The analysis shall include a description of the causes (contributing sources) of the artifacts and a description of the steps taken to eliminate them. Again, imagery is helpful in identification of artifacts. Figure A-4 shows examples of artifacts that remain after automated post-processing and prior to manual post-processing of LIDAR data. Because a major portion of post-processing costs pertain to manual post-processing, which could consume as much as 80 percent of the total budget for a LIDAR project, the FEMA Lead may decide that it is not cost effective to require the bare-earth digital terrain data to be 100 percent clean and free of artifacts.

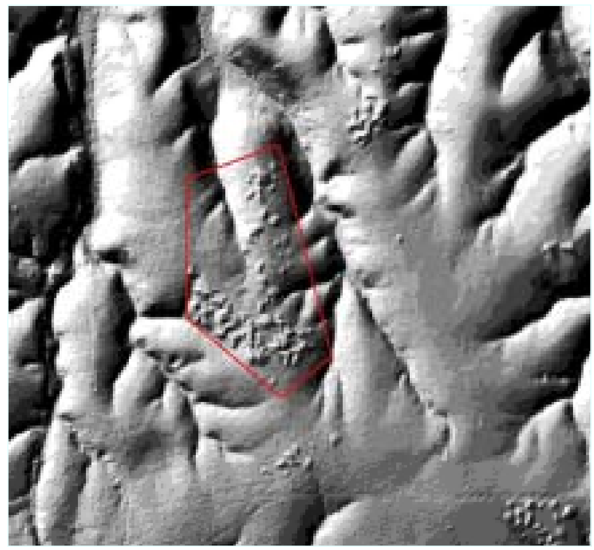

Figure A-4. Example of Artifacts

As with data voids, the severity of such artifacts depends on their size and location. In fact, the removal of such artifacts would create new data voids; therefore, the guidelines are essentially identical. Artifacts outside the floodplain, but inside the watershed, have no bearing on hydraulic modeling and can be neglected. Often, LIDAR cross sections can be "cut" in areas other than where the artifacts remain, and additional ground surveys are required only if necessary to "cut" cross sections through such artifact areas.

The exception to this policy is in the event that the Mapping Partner needs DEMs to be 100 percent clean of artifacts for reasons other than hydraulic modeling (e.g., for community GIS requirements). In such cases, other criteria must be applied to justify the additional costs for removal of all artifacts.

Outliers

During the RMSE calculation process in which survey checkpoints are compared to the interpolated TIN values, for example, discrepancies may exist between the two values. Some of the discrepancies may be larger than expected, especially in steep terrain or if a "blanket" of dense vegetation (e.g., mangrove, sawgrass, dense wheat fields) exists where the LIDAR may accurately survey the top surfaces of such vegetation rather than penetrating to the ground; in areas of complex topography (e.g., levees that look like hedge rows, boulders that look like haystacks); or in forested areas where removal of the top canopy may yield a lower canopy of underbrush that still does not represent the bare-earth terrain. If the number of larger-than-normal differences between the LIDAR-interpolated elevations and the elevations of surveyed checkpoints are limited, this may have a significant impact on the final RMSE calculation.

Outliers often occur as a result of the failure to achieve a true bare-earth surface from the vegetation removal process. A single outlier can override dozens or hundreds of accurate checkpoints, making the entire RMSE value appear to be poor. When this occurs, the coefficient of skew may indicate that the errors do not have a normal distribution, a sign that the RMSE calculation may be misleading (see Subsection A.8.6.3.) Having a large quantity of outliers may highlight improper post-processing. To deal with outliers, a criterion may be established to remove a small percentage of the total number of checkpoints surveyed that exhibit the largest discrepancies. Statisticians almost unanimously agree that errors exceeding the "3-sigma" level are outliers; the "3-sigma" level provides confidence at the 99.75-percent confidence level, enabling only the worst 0.25percent of a dataset to be discarded as outliers. Less stringent criteria consider the discarding of the worst 1, 5, or 10 percent of the data. Allowing 10 percent outliers would be in accord with the NMAS, where the worst 10 percent of all checkpoints are treated as outliers that can be discarded, regardless of size. The RPO, PO, or other FEMA Lead is free to consider the provision of a limited percentage of outliers, especially if the skew calculation indicates that the dataset lacks a normal distribution. The option to collect additional checkpoints to replace the outliers may be considered.

A.8.3.2 System Calibration [February 2002]

LIDAR system components are most effectively tested and calibrated by the equipment manufacturer. Therefore, the assigned Mapping Partner shall provide FEMA with evidence of manufacturer calibration.

In addition to evidence of manufacturer calibration of system components, the assigned Mapping Partner shall submit evidence that the total LIDAR system was calibrated prior to project initiation for the purposes of identifying and correcting systematic errors. Proper system calibration requires repetitive overflight of terrain features of known and documented size and elevation using flight paths similar to those that will be used in the study area. For some projects, daily in-situ calibrations may be required.

A.8.3.3 Flight Planning [February 2002]

Planning a flight path that considers all aspects of data collection is critical to the success of the mission. An analysis of the project area, project requirements, topography, proximity to restricted air space, and other factors will determine the flight path configuration. The mission should include parallel flight lines and, for quality control purposes, at least one cross flight line. The spacing between the flight lines will depend on the desired amount of sidelap between swaths and the terrain.

The density and accuracy of data generated by different equipment vary widely. The assigned Mapping Partner shall have the flexibility of providing a flight path to create the necessary point density to meet the posting and accuracy requirements and minimize the occurrence of data voids.

The assigned Mapping Partner shall check the Position Dilution of Precision (PDOP) in the study area. The PDOP is an indicator of the positional accuracy that can be derived from the current GPS satellite geometry, which varies continuously; the smaller the PDOP number, the higher the data quality.

The assigned Mapping Partner shall document mission date, time, flight altitude, airspeed, scan angle, scan rate, laser pulse rates, and other information deemed pertinent. For a sample mission data recordation checklist, refer to Table A-4 at the end of this Appendix.

A.8.3.4 Global Positioning System (GPS) Base Stations [February 2002]

The assigned Mapping Partner shall select the GPS base stations carefully to ensure reliable differential processing of airborne GPS data. NGS recommends the simultaneous use of two GPS base stations during the mission. Either public- or private-domain GPS base stations are suitable for use for this purpose, provided they are within the acceptable GPS baseline limits. Normally, 20-kilometer baseline lengths are maximum for high-accuracy LIDAR surveys, where the airborne GPS error component should contribute no more than 5 centimeters to the vertical error budget.

Where possible, GPS base stations must have ellipsoid heights to an accuracy of 2 centimeters relative to the Continuously Operating Reference Stations or the HARN. The assigned Mapping Partner shall use high-quality, dual-frequency GPS receivers and associated antennae at the GPS base stations.

A.8.4 Accuracy Reporting Methodology [February 2002]

In FGDC-STD-007.1 and FGDC-STD-007.2, FGDC documented a common methodology for determining and reporting the accuracy of horizontal and vertical coordinates for geodetic control points (survey monuments). Additional guidance is included in NGS-58 (NOAA, 1997).

A.8.5 Post-Processing of Data [February 2002]

For hydraulic modeling, the assigned Mapping Partner shall provide high-resolution, high-accuracy, bare-earth ground elevation data. To restrict data to ground elevations only, the Mapping Partner shall remove elevation points on bridges, buildings, and other structures, and on vegetation from the LIDAR-derived data. In addition to randomly spaced LIDAR points, before and after removal of data associated with structures and vegetation, the Mapping Partner shall produce a bare-earth TIN as well as a DEM, with the minimum regular point spacing, no greater than 5 meters, allowed by the data in eastings and northings. The Mapping Partner shall use TIN linear interpolation procedures when validating the vertical accuracy of the elevation dataset. The Mapping Partner shall normally perform the accuracy assessments on the TIN and not on the DEM, which is a derived product of slightly lower accuracy.

Using digital orthophotos, stereo photogrammetry, or other source materials, the assigned Mapping Partner shall produce breaklines for the following:

- Stream centerlines;
- Drainage ditches;
- Tops and bottoms of streambanks;
- Ridge lines;
- Road crowns;
- Levees;
- bulkheads,;
- Seawalls;
- Road/highway embankments; and
- Selected manmade features that constrict or control the flow of water (e.g., curb lines).

When merged with mass points, breaklines are used to enforce TIN triangle edges. The assigned Mapping Partner also shall specify the sources and accuracy of breakline data. Breaklines are not to be depicted for small culverts that pass under roads unless those culverts (or ditches leading in and out of them) are visible on available imagery without the use of photogrammetric stereo compilation which is normally too expensive for this purpose.

A.8.6 Quality Assurance/Quality Control [February 2002]

The assigned Mapping Partner has primary responsibility for performing QA/QC reviews of the LIDAR-derived data. This QA/QC review process shall include reviews of flight alignments and completeness of supporting data (e.g., cross sections and profiles). Until LIDAR technology and procedures become mature, FEMA will normally provide funding for independent QA/QC testing.

A.8.6.1 Vertical RMSE Standards [February 2002]

When systematic errors have been corrected and remaining errors have a normal distribution, the NSSDA uses the RMSE to estimate both horizontal and vertical accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. If those differences are normally distributed and average zero, 95 percent of any sufficiently large sample should be less than 1.96 times the RMSE. Therefore, vertical RMSE of 18.5 centimeters is often referred to as equivalent to 2-foot contours, or "37-centimeter accuracy at the 95-percent confidence level." Following that convention, the vertical accuracy of any digital elevation dataset is defined as 1.96 times the RMSE of linearly interpolated elevations in that dataset, as compared with known elevations from high-accuracy test points.

For the NFIP, TINs (and DEMs derived therefrom) should normally have a maximum RMSE of 18.5 centimeters, equivalent to 2-foot contours, in flat terrain; and a maximum RMSE of 37 centimeters, equivalent to 4-foot contours, in rolling to hilly terrain. The Mapping Partner shall field verify the vertical accuracy of this TIN to ensure that the 18.5- or 37.0-centimeter RMSE requirement is satisfied for all major vegetation categories that predominate within the floodplain being studied.

A.8.6.2 Ground Cover Categories [February 2002]

The assigned Mapping Partner shall separately evaluate and report on the TIN accuracy for the main categories of ground cover in the study area, including the following:

1. Bare-earth and low grass (e.g., plowed fields, lawns, golf courses);
2. High grass, weeds, and crops (e.g., hay fields, corn fields, wheat fields);
3. Brush lands and low trees (e.g., chaparrals, mesquite);
4. Forested, fully covered by trees (e.g., hardwoods, evergreens, mixed forests);
5. Urban areas (e.g., high, dense manmade structures);
6. Sawgrass; and
7. Mangrove.

Ground cover Categories 1 through 5 above are fairly common everywhere. FEMA experience with Categories 6 and 7 is that sawgrass and mangrove each have vegetation so dense that LIDAR pulses do not penetrate to the ground, but instead map the top reflective surface. The assigned Mapping Partner must treat such areas like "obscured terrain" with conventional photogrammetry whereby bare-earth elevations within such vegetation category polygons can only be estimated by interpolating elevations from ground points surrounding such polygons.

The assigned Mapping Partner may further subdivide and expand the above definitions to better accommodate the predominant vegetation types in the study area. The Mapping Partner shall distribute sample points throughout each category area being evaluated and not group the sample points of the same type in a small sub-area.

The assigned Mapping Partner shall select a minimum of 20 test points for each major vegetation category identified. Therefore, a minimum of 60 test points shall be selected for three (minimum) major land cover categories, 80 test points for four major categories, and so on. The Mapping Partner shall consider establishing test points when planning field surveys to gather cross-section data for hydraulic modeling. Confidence in the calculated RMSE value increases with the number of test points and is a function of sample size. By specifying a minimum of 60 checkpoints (20 each in three or more land cover categories), FEMA is specifying that 60 test points are the minimum necessary for a practical level of confidence in the calculated RMSE statistic, but recognizing that a higher number of checkpoints will provide higher confidence that performance standards have been achieved.

The assigned Mapping Partner shall select the test points in terrain that is flat or uniformly sloped within 5 meters in all directions. The uniform slope must not exceed 20 percent. The test points must never be located near to breaklines, such as bridges or embankments. Test points on sloping or irregular terrain would be unreasonably affected by the linear interpolation of test points from surrounding TIN points and, therefore, shall not be selected.

A.8.6.3 Analysis of Error Frequency Distribution [February 2002]

The RMSE process assumes that errors have a normal distribution (bell curve) with zero mean and that all systematic errors have been removed. This is rarely the case, especially with LIDAR data. Some systematic errors or biases remain undetected, even after regular calibrations of LIDAR systems. This subsection addresses statistical processes for evaluating whether the errors have a central tendency close to zero, evaluating the measure of general variability, and evaluating the measure of skewness. Unfortunately, no hard and fast rules to pinpoint problems exist, but each of the statistical processes mentioned have some value in detecting the potential presence of systematic errors, for which further investigations are warranted, especially if the RMSE calculation fails to pass the vertical accuracy criteria established for the project.

<u>Histograms</u>

The most common form of error analysis is to develop a histogram of all errors. If a dataset tabulates errors for all checkpoints, a histogram might show how many of those errors fell within different 5-centimeter ranges; for example, graphing the number of errors between the following error values: -50centimeters, -45 centimeters, -40 centimeters, -35 centimeters, -30 centimeters, -25 centimeters, -20 centimeters, -15 centimeters, -10 centimeters, -5 centimeters, 0, +5 centimeters, +10 centimeters, +15 centimeters, +20 centimeters, +25 centimeters, +30 centimeters, +35 centimeters, +40 centimeters, +45 centimeters, and +50 centimeters.

Histograms illustrate whether the errors are unimodal, bimodal, or multimodal; have small or large variability; or are skewed on either the positive or negative side. Often, such histograms for LIDAR data appear to approximate a normal distribution, except that it does not have a zero mean; this would appear to indicate the presence of uncorrected systematic error. Separate histograms for individual land cover categories often depict significantly different characteristics that help to understand LIDAR system performance (including post-processing) in the different categories. Figure A-5 is an example of a histogram reflecting checkpoint errors from a LIDAR dataset that does approximate a normal error distribution.

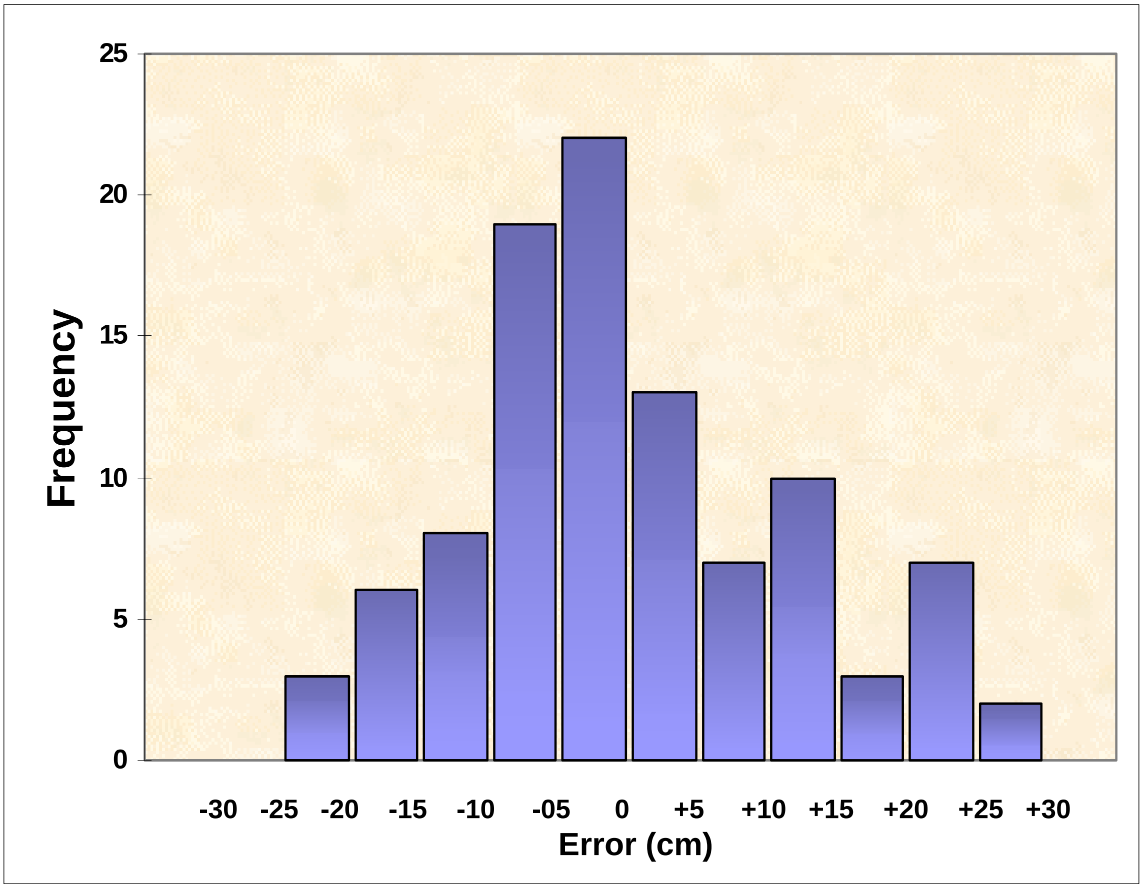

Figure A-5. Histogram for Checkpoint Errors in LIDAR Dataset

Measures of Central Tendency

Three common measures of the central tendency of errors in a dataset may be used to quantify the nearness to or departure from the expected central tendency of zero:

- The ***Arithmetic Mean*** is the sum of all the errors, divided by the number (n) of checkpoints. When the mean error is large, this is an indicator that systematic errors may be present.
- The ***Median*** is the value at which there are as many larger errors as there are smaller errors.
- The ***Mode*** is the value at which the greatest number of errors is concentrated. In a histogram, the mode is the error value or error range which has the highest ordinate value at the peak of the histogram.

General Variability

Various measures of general variability for statistical data exist, including range, average deviation, RMSE, standard deviation, and variance. However, the industry standard for geospatial data is the RMSE. For the dataset used to compute the histogram in Figure A-5, $RMSE_z$ = 11.7 centimeters, which equates to vertical $Accuracy_z$ of approximately 22.9 centimeters at the 95-percent confidence level. The standard deviation (σ or sigma) is primarily used for determination of statistical outliers (i.e., elevation errors that exceed the 3-sigma level).

Skewness

Skewness is the condition of being asymmetrical or lopsided, and departing from the expected normal distribution shown by the bell curve. The coefficient of skewness (a unitless number) is used to compute the asymmetry of the errors about the arithmetic mean error. When the absolute value of the skew exceeds 0.5, this means that the error distribution is asymmetrical and may not represent a normal distribution. Mapping Partners should investigate all datasets with skew values exceeding $\pm$0.5 to determine whether there is a valid reason why the errors do not have a normal distribution (a basic assumption in calculation of RMSE values). For the dataset used to compute the histogram in Figure A-5, the skew is 0.429. The skew is computed automatically by Microsoft Excel and other spreadsheets, and uses calculations of the second and third central moments of the dataset.

The coefficient of skew is zero when the error distribution is perfectly symmetrical.

A.8.6.4 Error Assessment [February 2002]

When a LIDAR dataset does not pass the vertical accuracy standard, the assigned Mapping Partner must identify the cause of the errors. Systematic corrections should never be applied without first identifying the cause of errors. Many factors could have contributed to errors, including the following:

- The LIDAR aircraft may have flown at too high of an altitude, causing IMU angular errors to propagate to larger errors on the ground from a higher altitude.
- The GPS baselines may be too long, flying too far from the GPS base stations, and causing larger than normal errors in airborne GPS positions.
- The scan angle may have been too large or the airspeed too fast, causing wider point spacings and fewer laser pulses that were near vertical.
- The satellite PDOP may have been too high, reducing the accuracy of airborne GPS positions.
- The post-processing algorithms may have been applied incorrectly.
- Systematic errors with the airborne GPS, IMU, or laser scanner may have occurred.

The list of potential causes is a long one because the process is complex.

Many of the statistical tools described in Subsection A.8.6.3 may point to the apparent existence of systematic errors. The standard procedures listed below shall be used by Mapping Partners to trouble shoot total LIDAR systems in order to isolate systematic errors:

Assessments by Land Cover

If ground cover category 1 (bare earth and low grass) does not pass the vertical accuracy standard, the potential causes are different from potential causes when vegetated or urban areas do not pass. Ground cover category 1 essentially should always pass accuracy standards, unless something systematic is wrong. Daily calibration tests help to confirm that the system performed well at the calibration test site (on that same day with the same sensor), and the calibration site normally includes bare-earth terrain and short grasses. If ground cover category 3 (brush lands and low trees) or ground cover category 4 (forested, fully covered by trees) alone do not pass the vertical accuracy standard, the most probable causes are shortcomings in the vegetation-removal procedures used in post-processing. If ground cover category 5 (urban areas) does not pass the vertical accuracy standard, something systemic about urban buildings may cause the errors.

Assessments by Error Locations

The assigned Mapping Partner shall assess errors relative to its location within flight lines, or near the beginning or end of swaths. This may indicate IMU errors or high satellite residuals due to aircraft banking causing cycle slips and multipath.

Assessments by Dates/Sensors

When LIDAR datasets are flown on different dates, or with different sensors, the assigned Mapping Partner must consider these variables in the error analyses.

Airborne GPS Verification

The assigned Mapping Partner shall examine GPS flight trajectories, compare the forward and reverse flight trajectories' combined separation, check satellite health, check geomagnetic observations, and verify the following:

- PDOP;
- GPS satellite residuals;
- Satellite phase RMS;
- Weighting adjustments when two or more differential base stations are used;
- Base station distance separation;
- Position standard deviations;
- Vertical datum used; and
- Correct application of Geoid99 (or newer) calculation of orthometric heights.

Inertial Measurement Unit Verification

The assigned Mapping Partner normally shall do the following to verify the accuracy of the IMU:

- Review the Kalman filter, the measurement residual ratio, and the consecutive measurement rejections settings.
- Confirm that the IMU was in "fine align" mode for the whole of the dataset.
- Check the accelerometer drift and scale facto, and the gyro drift and scale factor to ensure they are within specifications.
- Compare the GPS trajectory with the recomputed IMU trajectory and investigate large discrepancies.
- Review the IMU to lever arm parameter measurements and ensure they are entered correctly in the proper reference system.

Laser Range Verification

The assigned Mapping Partner shall normally do the following to verify the accuracy of the laser ranges:

- Review the raw laser ranges.
- Identify the areas of high dropouts (no returns) and correlate them to justifiable features.
- Review the scanner mirror angles (galvanometers or micro-controllers).
- Examine the intensity images, if they were collected.
- Review the system-generated error log sheets.

Total System Verification

To verify the accuracy of the whole system, the assigned Mapping Partner shall do the following:

- Review the calibration flights and compare them to the system flight parameters.
- Use CAD software to analyze the individual flightlines and to verify pitch, roll, and heading errors.
- Check overlap for roll and scaling errors.
- Check the ground features for pitch (e.g., buildings, bridges).
- Check scaling errors if water bodies exist.
- Compare cross-flight data for attitude.

- Verify vegetation removal procedure and review parameters if data were "corrected" or adjusted for pitch, roll, and heading errors. For example, was the iteration angle too high for the terrain type? Is the morphological window within a reasonable size for area features (e.g., is it too large and removes key components such as large dunes)?

Systematic Error Corrections

It is relatively easy to determine the magnitude of systematic errors and adjust all data accordingly; however, the assigned Mapping Partner must not "correct" such errors until the error source is clearly identified and documented. The Mapping Partner must report systematic errors to the FEMA Lead for review before systematic reprocessing of data that initially failed to pass the accuracy criteria.

A.8.6.5 Cross Flight Verification [February 2002]

To supplement the QA/QC process for LIDAR data, the assigned Mapping Partner may employ different optional techniques to check both for accuracy and precision. The balance is to address the need for additional verification checkpoints with cost-effective methods that aid in identifying the internal consistency (precision) of LIDAR data. Two GPS techniques that may be used are the *continuous kinematic* and *Real Time Kinematic (RTK)* techniques. The continuous kinematic technique collects positional data every epoch while maintaining fixed ambiguities on a minimum of five satellites. In the event of loss of lock on satellites, the integer ambiguities must be recomputed to their fixed integer value before a sub decimeter position can be calculated. Post processing is required to obtain the positional data. RTK is similar to continuous kinematic except that the data do not need to be post-processed. The estimated ambiguities are fixed to their integer values and positional data are calculated and stored in real time. Both methods are efficient for GPS surveys along highways.

With both types of GPS procedures, the process the assigned Mapping Partner must follow is to survey checkpoints perpendicular to the LIDAR flight paths at different strategic locations, with these additional checkpoints along roads or highways that transect the survey area. The Mapping Partner shall conduct surveys close to the center of roads and highways, avoiding bridges, elevated roads, or roads with steep embankments so that LIDAR points can be interpolated accurately without concern for steep slopes. If the flights are flown north to south, then the checkpoints must traverse east and west across the project area. A minimum of three cross lines must be measured, one at each end of the flight lines and another through the center. Typically, the weakest data will be at the beginning of the flight line if the GPS and IMU have not stabilized; this is due to the turning of the aircraft. The center cross line will help identify if the airborne data are stabilized.

Ideally, checkpoints should have a minimum point spacing of one-half the LIDAR swath width to ensure each swath has at least one checkpoint. Increasing the number of cross-flight checkpoints will assist the assigned Mapping Partner in verifying confidence within the data. Because such surveys are less accurate than the surveys of checkpoints to NGS-58 5-centimeter standards, the Mapping Partner shall not mix these additional verification points with the survey checkpoints used to compute the vertical RMSE or $Accuracy_z$. However, this is a relatively inexpensive way to generate a relatively large number of somewhat less-accurate checkpoints when the Mapping

Partner is concerned that the 60, 80, or 100 checkpoints (20 each in the major land cover categories) are insufficient for providing a high degree of confidence in the accuracy statistics.

A.8.7 Deliverables [February 2002]

All data and products associated with contract deliverables shall meet or exceed relevant NSSDA standards and fully comply with the FGDC metadata format standard with the provisions in the contract. The assigned Mapping Partner shall use the requirements in Appendix L of these Guidelines as a guide for preparing and submitting deliverable products to FEMA in digital format.

A.8.7.1 Pre-Project Deliverables [February 2002]

Prior to data collection, the assigned Mapping Partner shall submit the following to the FEMA Lead or a Mapping Partner designated by the FEMA Lead:

- A map (typically a USGS map is desirable) showing the study area boundaries and flight path, at a medium scale (1:24,000) or small scale (1:50,000);
- Documentation specifying altitude, airspeed, scan angle, scan rate, LIDAR pulse rates, and other flight and equipment information deemed appropriate; and
- A chart of areas of high PDOP or a list showing the time of the beginning and end of high PDOP.

A.8.7.2 Post-Project Deliverables [April 2003]

Following project completion, the assigned Mapping Partner shall submit the following to the FEMA Lead or a Mapping Partner designated by the FEMA Lead:

- A LIDAR system data report;
- A flight report;
- A ground control report;
- Ellipsoid model used as part of the collection;
- Geoid model used to compute orthometric heights;
- Data processing procedures for selection of postings, and all orthometric values of x, y, and z coordinates for LIDAR returns. Elevations shall be orthometric heights; and
- A system calibration report.

The LIDAR system data report shall include discussions of the following:

- Data processing methods used, including the treatment of artifacts;

- Final LIDAR pulse and scan rates;
- Scan angle;
- Capability for multiple returns from single pulses;
- Accuracy and precision of the LIDAR data acquired;
- Accuracy of the topographic surface products;
- Any other data deemed appropriate;
- Companion imagery, if any; an
- A digital spatial index showing the orientation of all data tiles within the project site with tile labels corresponding to the CD (or other media) ID and file name on that CD.

The flight report shall document mission date, time, flight altitude, airspeed, and other information deemed pertinent. The report shall include information about GPS-derived flight tracks, provide a detailed description of final flight line parameters and GPS controls (i.e., benchmarks), and include ground truth and complementary reference data.

The ground control report shall include, at a minimum, all pertinent base station information and mission notes, including information on GPS station monument names and stability.

A.8.7.3 Delivery of Digital Data [April 2003]

In addition to the pre- and post-project deliverables described above, the assigned Mapping Partner shall submit the following:

- All raw datasets, dataset of survey points filling voids, dataset of transects (if generated), bare-earth DEM data, and breaklines in separate data files; and
- Uniformly spaced DEM(s), on ISO 9660 standard CD-ROM (or DVD) media in a format specified in Appendix L.

The assigned Mapping Partner shall deliver raw datasets and LIDAR system data, including orthometric heights for each point, in comma-delimited ASCII files in x, y, and z format. The Mapping Partner shall deliver the DEM in the format designated in the Table A-4 checklist. The Mapping Partner also shall flag raw datasets from sidelap and overlap areas of separate flight lines. The Mapping Partner shall produce breaklines which shall contain a flag record that identifies them as breakline features and identifies their source and accuracy. The Mapping Partner shall submit raw datasets in tiles or data models matching those of the DEM. The Mapping Partner also shall submit documentation on the ellipsoid model and geoid model used to obtain orthometric heights. The Mapping Partner shall ensure that all deliverables conform to the projection, datum, and coordinate system requirements specified in the SOW, MAS, or other contractual agreement with FEMA. File sizes cannot exceed 1 gigabyte, unless otherwise specified by the FEMA Lead. Each file shall be organized to facilitate data manipulation and processing.

A.8.8 Acceptance/Rejection **[February 2002]**

The terms of acceptance/rejection in Subsection A.7.5.5 shall apply.

Table A-4. LIDAR System Mission Data Collection Checklist

Notes	A. Data collection (each flight)
	1. Record flight date and time.* 2. Record flight altitude(s).* 3. Record LIDAR system scan angle, scan rates, and pulse rates.* 4. Record time LIDAR system receiver is activated/ deactivated.* 5. Record all Position Dilution of Precision values.* 6. Record height of instrument (before and after flight). 7. Record on-board antenna offsets. 8. Note any site obstructions at GPS base station(s). 9. Record airborne and ground-site GPS receiver types and serial numbers. 10. Record ground site GPS station monument names and stability.* 11. Record flight staff.
Notes	**B. Data handling (each flight)**
	1. Record that all files have been labeled correctly and cross-indexed. 2. Record analyst name(s) responsible for processing and product generation. 3. List any auxiliary information used during processing of LIDAR to generate products delivered. 4. List major data processing components used.

* Denotes Minimum Required Information

A.9 References **[February 2002]**

American Society for Photogrammetry and Remote Sensing. (2001). *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, Chapter 2 (Vertical Datums), Chapter 3 (Accuracy Standards), Chapter 5 (Photogrammetry), Chapter 7 (Topographic LIDAR), Chapter 12 (DEM Quality Assessment), Chapter 13 (DEM User Requirements), and Appendices A and B (Acronyms and Definitions).

American Society for Photogrammetry and Remote Sensing. (1995). Draft Aerial Photography Standards, *Photogrammetric Engineering and Remote Sensing*, Vol. 61, Number 9, pp. 1097-1103.

American Society for Photogrammetry and Remote Sensing. (1990). "ASPRS accuracy standards for large-scale maps," *Photogrammetric Engineering and Remote Sensing*, Vol. 56, No. 7, pp 1068-1070.

Bureau of the Budget. (1947). *National Map Accuracy Standards,* Washington, DC.

Federal Geographic Data Committee. (1999). *Content Standards for Framework Land Elevation Data (final draft),* FGDC, c/o U.S. Geological Survey, Reston, VA, www.fgdc.gov/standards/documents/standards/elevation/ele_199.pdf .

Federal Geographic Data Committee. (1998). FGDC-STD-007.1-1998, *Geospatial Positioning Accuracy Standards, Part 1: Reporting Methodology*, FGDC, c/o U.S. Geological Survey, Reston, VA, www.fgdc.gov/standards/documents/standards/accuracy/chapter1.pdf .

Federal Geographic Data Committee. (1998). FGDC-STD-007.2-1998, *Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks*, FGDC, c/o U.S. Geological Survey, Reston, VA, www.fgdc.gov/standards/documents/standards/accuracy/chapter2.pdf .

Federal Geographic Data Committee. (1998). FGDC-STD-007.3-1998, *Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy*, FGDC, c/o U.S. Geological Survey, www.fgdc.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf .

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. (1997). NOAA Technical Memorandum NGS-58, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm), version 4.3,* www.ngs.noaa.gov/PUBS_LIB/NGS-58.html.

U.S. Department of the Army, Corps of Engineers. (1994). Engineer Manual 1110-2-1003, *Hydrographic Surveying*, October 1994.

U.S. Department of the Army, Corps of Engineers. (1993). Engineer Manual 1110-1-1000, *Photogrammetric Mapping*.