Guidelines for Digital Elevation Data

Version 1.0

National Digital Elevation Program (NDEP)
May 10, 2004

PREFACE

With an ever growing demand for digital elevation data by Federal, state, and local governments, the National Digital Elevation Program (NDEP) was established to promote the exchange of digital elevation data among government, private, and non-profit sectors and the academic community, and to establish standards and guidance that will benefit all users.

The NDEP currently consists of representatives from the following organizations:

- U.S. Geological Survey (USGS)
- National Geospatial-Intelligence Agency (NGA)
- U.S. Army Corps of Engineers (USACE)
- National Oceanic and Atmospheric Administration (NOAA)
- Bureau of Land Management (BLM)
- National States Geographic Information Council (NSGIC)
- National Aeronautics and Space Administration (NASA)
- Natural Resources Conservation Service (NRCS)
- U.S. Department of Agriculture, Forest Service (USDA-FS)
- Federal Emergency Management Agency (FEMA)
- U.S. Census Bureau

For further information on the NDEP or these guidelines, visit the NDEP site at http://www.ndep.gov, or submit comments/questions by e-mail to elevation@ndep.gov.

FIGURES

TABLES

PART 1: CONTENT

The content portion of this guideline contains descriptions and definitions of elements that are inclusive of all agencies and organizations. Content is treated as general information. Elements requiring agency specific or unique treatments are deferred to the individual agency product specifications. Part 2 Elevation Product Descriptions contains links to participating agency product standards.

1.1 INTRODUCTION

1.1.1 Objective

The purpose of this document is to provide the member agencies of the National Digital Elevation Program (NDEP), as well as nonmember agencies, with guidelines and recommendations for acquiring digital elevation data in any of its various forms. Individual agencies may choose from flexible options to establish standards for their organizations. The following reasons are commonly cited for promoting and adhering to a common set of elevation guidelines or standards whenever possible and practical:

- Past data acquisitions have led to a wide variety of accuracy, resolution, datum, projection, product type, format, and other idiosyncrasies making these datasets difficult, if not impossible, to share among different agencies.
- The lack of guidelines and specifications, especially for high-resolution, high-accuracy elevation data, has caused some data acquisitions to cost more than necessary due to over-engineering, while other data purchases prove to be inappropriate for the intended application due to inadequate specifications.
- Because of continuous capability improvements, increasing numbers of providers, and varying system designs, new elevation technologies such as LIDAR and IFSAR are rapidly evolving. Sharing the lessons learned about these technologies by developing and refining a common set of elevation guidelines will reduce the chance of repeating mistakes across agencies and will help the purchaser acquire the required data as painlessly as possible the first time.

1.1.2 User Requirements Menu

In developing a content standard for digital elevation data required by any organization, the NDEP is adopting the flexible approach explained with working examples in the *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, published in 2001 by the American Society for Photogrammetry and Remote Sensing (ASPRS, 2001). Because content standards for digital elevation data will vary among different organizations with diverse needs, a User Requirements Menu is presented in table 1, with menu options explained in the following subsections. It is intended that each NDEP member agency establish default values, for the various menu options, to tailor a content standard for their needs. Whereas this document provides guidelines and may recommend default values, it is up to each NDEP member agency to establish its own content standard.

Table 1 User Requirements Menu

General Surface Description (choose one or more)

Elevation Surface (1.2.1)
☐ Digital surface model (first reflective surface)
☐ Digital terrain model (bare earth)
☐ Bathymetric surface ☐ Point cloud
☐ Mixed surface

Elevation Type (choose one) (1.2.2)
☐ Orthometric height
☐ Ellipsoid height
☐ Other ________________

Model Types (1.3) (choose one or more) * Designate either feet or meters
☐ Mass points ☐ Grid (post spacing = ___ feet/meters) * ☐ Contour interval = _____ft /m *
☐ Breaklines ☐ Grid (post spacing = ____ arc-seconds) ☐ Cross Sections
☐ TIN (average point spacing = ___ feet/meters) * ☐ Other (For example, concurrent image capture)

Source (1.4) (choose one)
☐ Cartographic ☐ Photographic ☐ IFSAR ☐ LIDAR ☐ Sonar
If Multi-return system:
☐ First return ☐ Last return ☐ All returns

Vertical Accuracy (1.5.1.1) (choose one)
☐ Fundamental Vertical Accuracy$_z$ = __ (ft or meters) at 95 percent confidence level in open terrain = RMSE$_z$ x 1.9600
☐ Supplemental Vertical Accuracy$_z$ = __ (ft or meters) = 95th percentile in other specified land cover categories
☐ Consolidated Vertical Accuracy$_z$ = __ (ft or meters) = 95th percentile in all land cover categories combined

---

Horizontal Accuracy (1.5.1.2) (choose one)
☐ Accuracy$_r$ = ___ ft or meters
Horizontal accuracy at the 95 percent confidence level (Accuracy$_r$) = RMSE$_r$ x 1.7308

Surface Treatment Factors (1.5.4) (optional – refer to the text)
Hydrography
Man-made structures
Special earthen surfaces
Artifacts
Special Surfaces

Horizontal Datum (1.6.1) (choose one)
☐ NAD 83 (default)
☐ WGS 84

Vertical Datum (1.6.2) (choose one)
☐ NAVD 88 (default) ☐ MSL
☐ MLLW ☐ Other _____

Geoid Model (1.6.3) (choose one) ☐ GEOID03 ☐ Other _____

Coordinate System (1.7) (choose one)
☐ UTM zone ______ ☐ State Plane zone ______
☐ Geographic ☐ Other _____

Units (1.7) Note: For feet and meters, vertical (V) units may differ from horizontal (H) units
☐ Feet to ___ decimal places ☐ V ☐ H ☐ Decimal degrees to ___ decimal places
☐ Meters to ___ decimal places ☐ V ☐ H ☐ DDDMMSS to ___ decimal places
Feet are assumed to be U.S. Survey Feet unless specified to the contrary

---

Data Format (1.8) (Specify desired format(s) for each Product Type. See text for examples.)
Product 1 ____________________ Formats ______________________________
Product 2 ____________________ Formats ______________________________
Product 3 ____________________ Formats ______________________________

File size (1.9) (specify acceptable range) ___________ Mb / Gb / Other _________

File Extent
Boundary: Rectangular
x-dimension _____ m / ft. / degrees / other ___
y-dimension _____ m / ft. / degrees / other ___
NonRectangular
Bndry name ______________________
Coordinate source ________________
Over-edge buffer width: ____________________________

Metadata compliant to the "Content Standards for Digital Geospatial Metadata" is highly recommended.

1.1.3 Relationship to Existing Standards

Recognizing that many applications and individual requirements exist for elevation data, this document provides flexible guidelines and general recommendations. These recommendations and guidelines may change fairly frequently to accommodate new technologies, capabilities, data models and other factors affecting elevation data. However, existing data standards are referenced, where appropriate, to assist members in determining what established testing methods, data formats, etc., may best meet their needs. If new standards are developed by independent organizations or by NDEP members and are deemed suitable for general use, references will be included within this document.

1.1.4 Standards Development Procedures

New content standards will be developed by NDEP member agencies only when existing standards are inadequate and a new standard is necessary and appropriate. The criteria for development of new "standards" as opposed to "guidelines" are: 1) a procedure, system, or data requirement is to be established for consistent use by NDEP members, and 2) the procedure, system, or data requirement is anticipated to be applicable for at least 5 years.

Development of standards may be undertaken by NDEP agency groups or may be commissioned to academic, industry, or professional organizations.

1.1.5 Maintenance

These guidelines, used in the development of agency standards, will be revised based on recommendations of any sponsoring agency and concurrence by NDEP member agencies.

1.2 GENERAL SURFACE DESCRIPTIONS

1.2.1 Elevation Surfaces

A digital elevation surface is usually characterized as one of five general types (digital surface model or first reflective surface, digital terrain model or bare-earth surface, bathymetric surface, mixed surface, or point cloud) depending on the features represented:

1.2.1.1 Digital Surface Model (DSM) or First Reflective Surface

A digital surface model (DSM) represents the highest reflective surface of ground features captured by the sensor. This surface may also be referred to as the first reflective surface or LIDAR first-return. The DSM may include treetops, rooftops, and tops of towers, telephone poles, and other natural or manmade features; or it may include the ground surface if there is no vegetative ground cover. Photogrammetry, IFSAR, LIDAR and sonar can all provide this type of surface, yet characteristics such as accuracy and degree of detail (ability to resolve desired surface features) may vary significantly across technologies and even within the same technology. With sonar, the DSM may include sunken vessels and other artifacts, whereas the bathymetric surface (section 1.2.1.3) reflects the natural underwater terrain. Similarly, with photogrammetry, LIDAR, and

IFSAR the reflective surface may include any artifact present when the sensor mapped the area, including passing cars and trucks and similar features not normally considered to be part of a digital terrain model (section 1.2.1.2).

1.2.1.2 Digital Terrain Model (DTM) or Bare Earth Surface

The bare earth surface (lowest surface, last reflective surface, or LIDAR last-return) represents the surface of the "bare-earth" terrain, after removal of vegetation and manmade features. Such surfaces are generally referred to as Digital Terrain Models (DTMs). Photogrammetry has traditionally generated DTMs when elevations are generated by manual compilation techniques. Unless specified to the contrary, the bare-earth surface includes the top surface of water bodies, rather than the submerged surface of underwater terrain.

1.2.1.3 Bathymetric Surface

The bathymetric surface represents the submerged surface of underwater terrain.

1.2.1.4 Mixed Surface

Certain applications may call for a hybrid of these surface types. For example, a user may require a bare-earth surface in all vegetated areas, but a top surface of selected man-made structures. If the DTM is to be used for water flow studies, buildings may be desirable (because they obstruct the flow of water) but bridge deck surfaces are not desirable (because water flows under the bridge deck). Similarly, coastal studies may require a DTM of the bare-earth surface merged with the bathymetric surface.

While traditional photogrammetric compilation has been most commonly focused on generating either a first reflective surface or a bare-earth surface, the emergence of LIDAR and multi-band IFSAR technologies has proven cost-effective for nearly simultaneous production of multiple surface types. Multiple surface representations are useful for numerous applications, such as forest inventory studies or fire fuel studies, requiring a separate first-return vegetation surface and bare-earth surface for the same site. Similarly, airborne LIDAR bathymetry provides the elevation of the water surface as well as the bathymetric surface.

1.2.1.5 Point Cloud

A point cloud elevation file is generally a raw data file containing three-dimensional (3-D) point samples, i.e. single points with multiple elevations. An example of a point cloud file would be a LIDAR multi-return dataset where there may be multiple z-values for each x/y coordinate.

1.2.2 Elevation Types

Different elevation types (technically "heights") are explained below. Unless specified to the contrary, the "elevation" of any point is assumed to be its orthometric height.

1.2.2.1 Orthometric Height

The orthometric height is the height above the geoid as measured along the plumbline between the geoid and a point on the Earth's surface, taken positive upward from the geoid. Orthometric heights are traditionally obtained from conventional differential leveling where survey instruments are leveled to the local direction of gravity.

1.2.2.2 Ellipsoid Height

The ellipsoid height is the height above or below the reference ellipsoid, i.e., the distance between a point on the Earth's surface and the ellipsoidal surface, as measured along the normal (perpendicular) to the ellipsoid at the point and taken positive upward from the ellipsoid. This is the height obtained from GPS surveys (including LIDAR and IFSAR which utilize airborne GPS), prior to corrections for the undulation of the geoid. Ellipsoid heights are independent of the local direction of gravity.

1.2.2.3 Other Elevation Types

Bathymetric Depth

Bathymetry is normally measured in terms of water depths, expressed as positive numbers downward, below the tidal datum. On nautical charts, for example, minus signs are not depicted on bathymetric contours or soundings unless they are above Mean Lower Low Water (MLLW).

Geoid Height

The geoid height equals the undulation of the geoid, and it is the difference between the ellipsoid height and the orthometric height at a specified location. An elevation model of geoid heights is called the geoid model; for example, GEOID99 or World Geodetic System 1984 (EGM96), used to convert ellipsoid heights into orthometric heights, or vice versa.

1.3 MODEL TYPES

Digital elevation data are modeled in many different forms, to include mass points, breaklines, TINs, grids, contour lines, cross sections, and others, all in addition to individual bench marks or 3-D control points that provide survey control for these various data models.

1.3.1 Mass Points

Mass points are irregularly spaced points, each with x/y location coordinates and z-values. When generated manually, mass points are ideally chosen so that subtle terrain characteristics (i.e., gradual variations in slope or aspect) are adequately represented in the data. However, when generated automatically; for example, by LIDAR or IFSAR scanners, mass point spacing and pattern depend upon the characteristics of the technologies used to acquire the data.

1.3.2 Breaklines

A breakline is used to represent a relatively abrupt linear change in the smoothness or continuity of surface slope or aspect. The two most common forms of breaklines are as follows:

A soft breakline ensures that known z-values along a linear feature are maintained (For example,, elevations along a pipeline, road centerline or drainage ditch, or gentle ridge), and ensures that linear features and polygon edges are maintained in a TIN (triangulated irregular network) surface model, by enforcing the breaklines as TIN edges. They are generally synonymous with 3-D breaklines because they are depicted with series of x/y/z coordinates. Somewhat rounded ridges or the trough of a drain may be collected using soft breaklines.

A hard breakline defines interruptions in surface smoothness, For example, to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although hard breaklines are often depicted as 3-D breaklines, they can also be depicted as 2-D breaklines because features such as shorelines and building footprints are normally depicted with series of x/y coordinates only, often digitized from digital orthophotos that include no elevation data.

1.3.3 Triangulated Irregular Network (TIN)

A fundamental data structure frequently used to model mass points from photogrammetry and LIDAR collection is the TIN. A TIN is a set of adjacent, nonoverlapping 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 and stores the topological relationship between triangles and their adjacent neighbors. The TIN structure is often superior to other data models derived from mass points because it preserves the exact location of each ground point sample.

1.3.4 Grids

Grids are the most common structures used for modeling terrain and bathymetric surfaces. There are several advantages to grids over other types of elevation model. A regular spacing of elevations requires that only one point be referenced to the ground. From this point, and using coordinate referencing information supplied with the grid, the location of all other points can be determined. This eliminates the need to explicitly define the horizontal coordinates of each elevation and minimizes the file size. Grids are also efficient structures for data processing.

1.3.4.1 Orthogonal Grid

An orthogonal-grid elevation model has z-values at regularly spaced intervals of ground distance in x and y ("post spacing" = $\Delta x = \Delta y$). The post spacing is usually specified in units of whole feet or meters. Actual grid spacing, datum, coordinate system, data format, and other characteristics may vary widely from grid to grid. The orthogonal grid shown in figure 1 depicts a Cartesian coordinate grid tiled to Cartesian corner coordinates. This grid/tile configuration is the easiest to produce and use for most applications. Figure 2 depicts a Cartesian coordinate grid tiled to regularly spaced geographic corners. Cartesian grids tiled on geographic corners require more complexity in data production and can cause data gaps at tile edges when the tiles are joined. Unless there is a specific requirement to tile Cartesian grids at regular geographic corners, the tiling scheme in figure 1 is the recommended method.

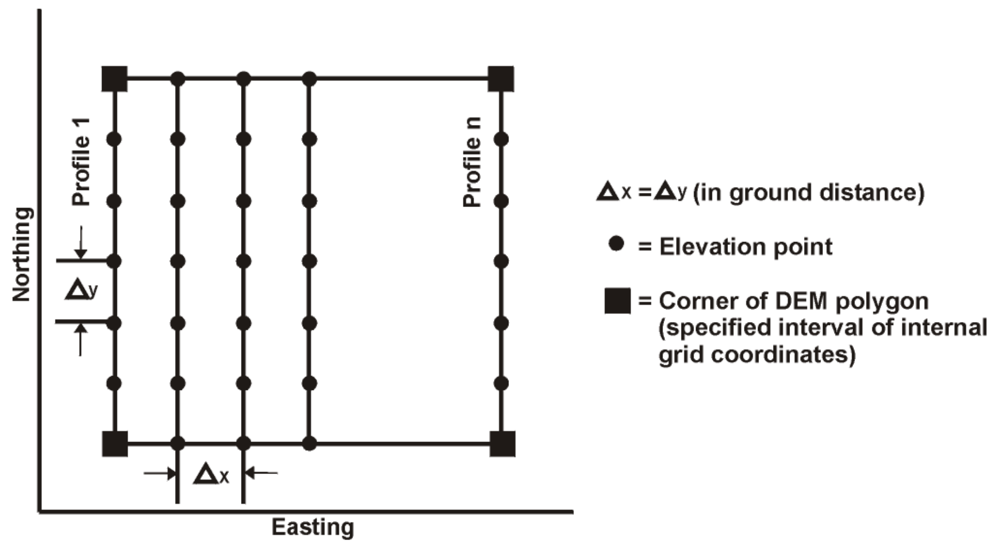

Figure 1 Cartesian Coordinate Grid with Cartesian Coordinate Boundary

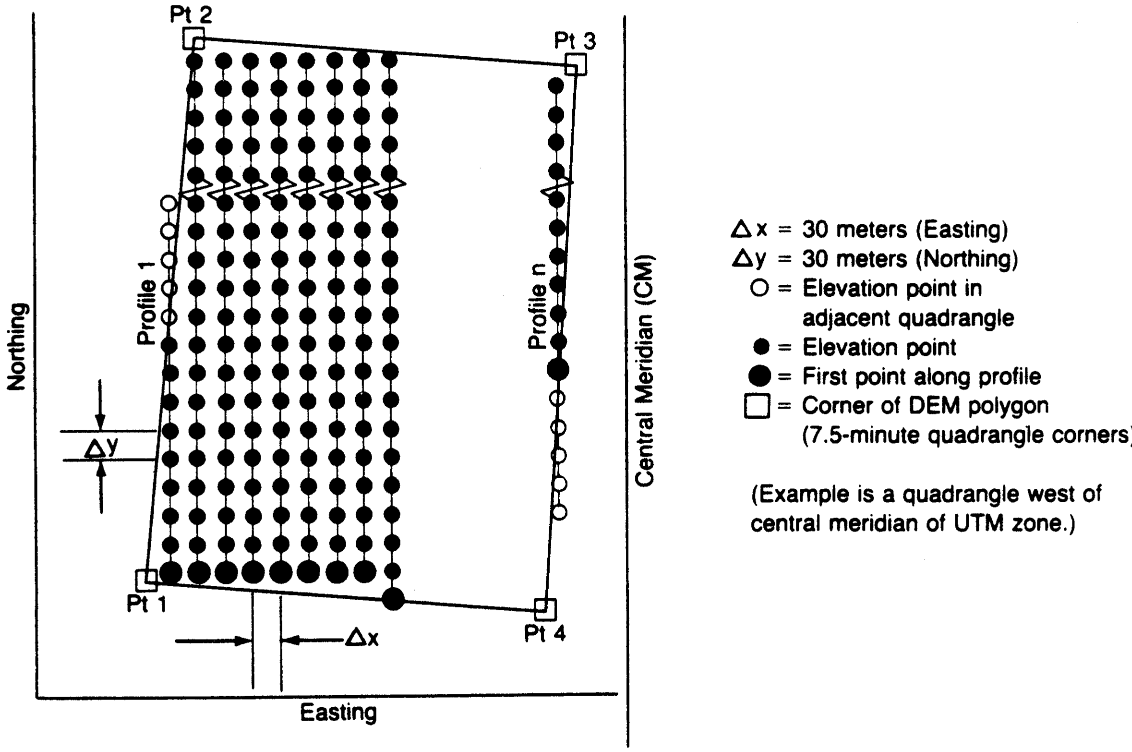

Figure 2 Cartesian Coordinate Grid with Geographic Coordinate Boundary. Example based on USGS 7.5-minute DEM.

1.3.4.2 Arc-Second Grid

An arc-second grid (or geographic-coordinate grid) is different from an orthogonal grid in that Δx is actually "Δ longitude" rather than a specified distance, and Δy is actually "Δ latitude" rather than a specified distance, with "Δ longitude" and "Δ latitude" both defined in terms of arc-seconds, arc-minutes, etc. One arc-second in northing and one arc-second in easting are nearly equal in arc-distance at the surface of the Earth near the Equator, but the arc-distance narrows in eastings north and south of the Equator because of the convergence of the meridians (figure 3). Because the ground distance of a second of longitude is substantially less than that of a second of latitude nearer the poles, the arc-second spacing of the x and y dimensions of the grid may be different to approximate uniform intervals of ground distance in both dimensions.

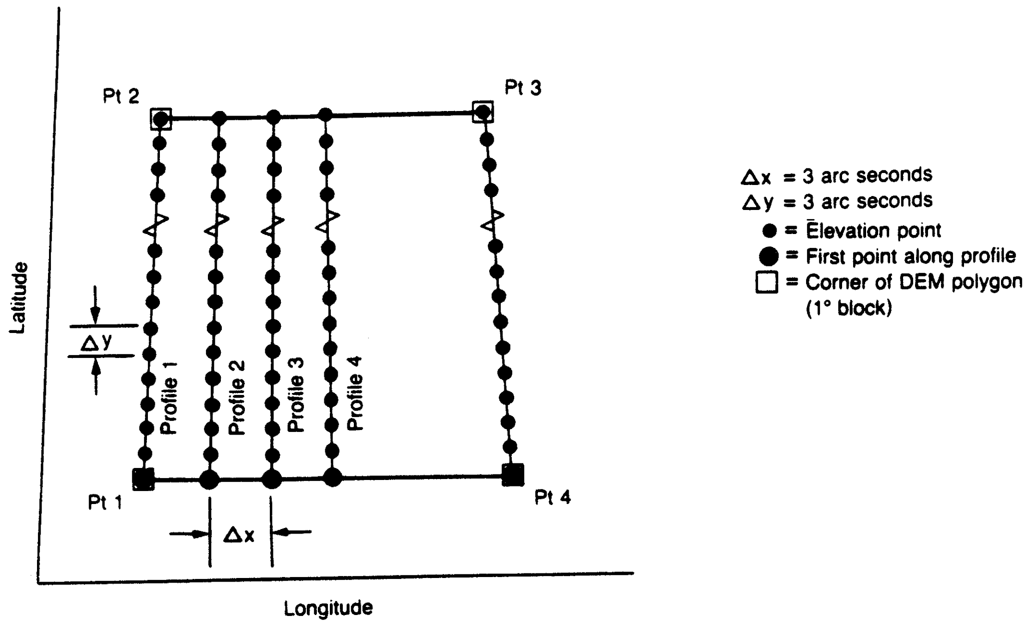

Figure 3 Geographic Coordinate Grid with Geographic Coordinate Boundary. Example based on USGS 1-degree DEM.

1.3.5 Contours

Contours are lines of equal elevation on a surface. A contour is also defined as an imaginary line on the ground, all points of which are at the same elevation above or below a specified reference surface (vertical datum).

1.3.6 Cross Sections

Cross sections are a string of x/y/z coordinates along a designated line from point A (zero station) to point B (terminal station). Figure 4 demonstrates FEMA's guidance on the spacing of cross section points across an entire floodplain (complete channel) or main channel within a floodplain. Cross section points may be surveyed conventionally on the ground, to include subsurface terrain, or "cut" from 3-D surfaces such as mass points, TINs, and DEMs for above-water surfaces.

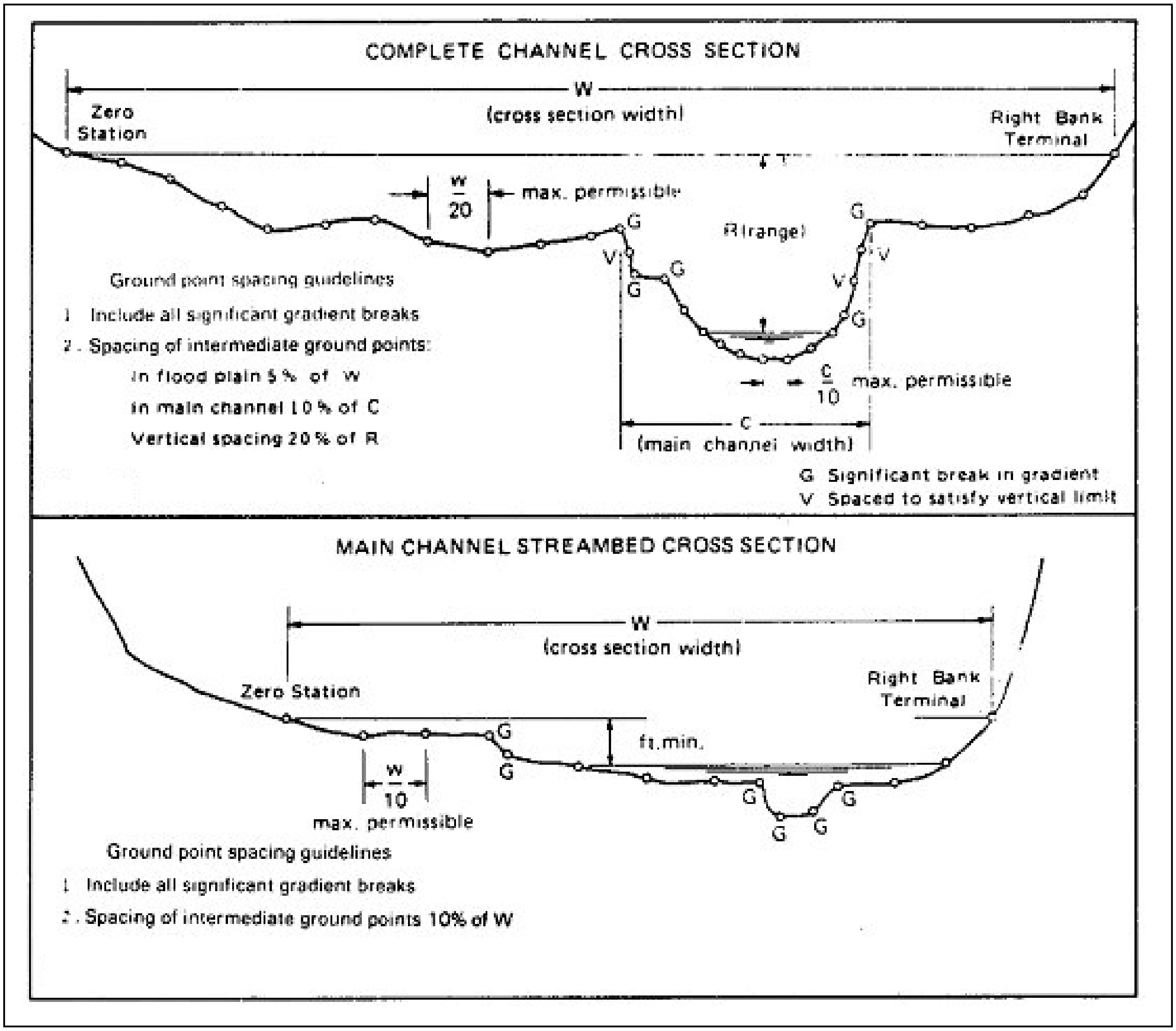

Figure 4 Examples of Cross Section Ground Point Spacing

1.3.7 Other Product Types

It may be advantageous to acquire other types of products simultaneously during elevation data capture. For example, recent ortho-imagery is useful during the edit and quality assurance phase of LIDAR processing. These images assist the operator with identifying the causes of surface anomalies and eliminating effects of surface cover during bare-earth processing. If recent images are not available, it may be necessary to capture the data during LIDAR collection.

1.3.8 Determining Horizontal Resolution (point spacing)

The density at which elevations are sampled during collection by a LIDAR or IFSAR system is referred to as the ground-sample distance (GSD). The average point spacing of irregularly spaced mass points (from LIDAR for example) or of uniformly spaced grid points is referred to as the horizontal resolution of the elevation model. The data density at which an elevation product is captured and modeled will determine the how well terrain features are represented and how accurately the dataset represents the terrain. The specified horizontal resolution should be chosen carefully, however, because it can have a significant effect on production cost and on data handling efficiency.

1.3.8.1 Horizontal Resolution for Feature Detection and Representation

The GSD specified for a collection system should be less than the minimum size of terrain features to be detected. Likewise, the horizontal spacing for the final product(s) should be chosen to most efficiently represent the size and frequency of terrain features to be modeled. For example, characterizing rough or dissected terrain may require collection at a 1-meter ground-sample distance and generation of 1 meter DEMs while gentle relief may be adequately collected with a 6-meter GSD and modeled with a 10-meter grid spacing. Widely varying terrain may require capture at a fine resolution but may be modeled at a variable resolution using a TIN. The TIN model retains a high point density over rough terrain but samples to a low point density over gentle terrain

When deriving a DEM from mass points or TINs, the mass points are normally collected at a higher GSD than the final resolution specified for the DEM. This approach provides multiple surrounding points for interpolation of DEM elevation posts. 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 approximately 3 meters, a denser dataset from which some points will be removed as a result of post-processing which eliminates points on manmade structures or dense vegetation.

1.3.8.2 Relationship Between Horizontal Resolution and Vertical Accuracy

The vertical accuracy of mass points, TINs or DEMs is a function of the horizontal resolution of the digital topographic data. There are no established rules that directly correlate the horizontal resolution of digital elevation data with vertical accuracy, but there is general agreement that TINs/DEMs equivalent to 1-foot contours should have narrower post spacing than TINs/DEMs equivalent to 2-foot contours, for example.

As reported in ASPRS, 2001, cartographers typically associate map scale with contour intervals as follows:

- Maps compiled at 1 inch = 100 feet with 1-foot contours are comparable to DEMs with post spacings of 1 meter
- Maps compiled at 1 inch = 200 feet with 2-foot contours are comparable to DEMs with post spacings of 2 meters

- Maps compiled at 1 inch = 500 feet with 5-foot contours are comparable to DEMs with post spacings of 5 meters
- Maps compiled at 1 inch = 1000 feet with 10-foot contours are comparable to DEMs with post spacings of 10 meters
- Maps compiled at 1 inch = 2000 feet with 20-foot contours are comparable to DEMs with post spacings of 20 meters.

From these correlations, it can be seen that it normally makes little sense to generate a DEM with a vertical accuracy equivalent to 1-foot contours if the DEM post spacing is 10 meters. However, there may be exceptions if the DEM is supplemented with breaklines. Normally, when breaklines are generated by alternative means to supplement the DEM data, then the average DEM post spacing may be relaxed. For example, for the equivalent of 2-foot contours, FEMA considers a 2-meter DEM post spacing to be appropriate if there are no supplemental breaklines, but 5-meter post spacings are adequate if limited breaklines, along shorelines and at the tops and bottoms of stream banks for example, are available for use in the hydraulic modeling of floodplains.

1.4 SOURCES

Cartographic Sources

It is common practice to utilize features from printed maps or digitized features from maps to create elevation models or to improve the accuracy of elevation data.

1.4.1.1 Hypsographic Features

Contour lines on existing topographic maps (For example, USGS 7.5-minute quadrangles) may be digitized in vector format to establish line strings of x/y coordinates with z-values for specified contours. Gridded DEMs may then be produced by interpolating at regular intervals between these attributed coordinate strings. TIN points may be interpolated at locations that optimally represent significant changes in slope. For more information on hydro-enforcement, see section 1.5.4.1.

1.4.1.2 Hydrographic Features

Shorelines of rivers, lakes and other hydrographic features may be digitized in vector format to establish 2-D (x/y) breaklines between the water surface and slope of the ground leading down to the water. Additional breaklines may be digitized for small stream centerlines, drainage ditches, and similar hydrographic features. Such breaklines, when combined with contour lines, are used to establish the direction of flow of rivers and streams. When known river elevations upstream and downstream are applied to 2-D breaklines, they can be converted into 3-D breaklines that gradually decrease from the known upstream elevation to the known downstream elevation. All such breaklines, whether 2-D or 3-D, may be "burned" into DEMs to enforce known drainage patterns and to drain "puddles." This is one form of "hydro-enforcement."

1.4.1.3 Transportation Features

Roads, railroads and bridges may also be digitized in vector format to establish breaklines that can be used to improve the accuracy of a DEM. A road may have a "soft breakline" along the crown, causing water to flow off the road into drainage ditches with "hard breaklines" on either side of the road. Bridges (and concrete box culverts) need to be carefully digitized to either delete elevations along the tops of the bridges, or to cut through the bridges with a breaklines to show that water passes under them. If an elevation is retained along the top of a bridge, a bare-earth surface DEM would erroneously appear to be dammed by the bridge, and water would not be able to flow under it. Therefore, when producing bare-earth surface DEMs, bridges require a form of hydro-enforcement. Similarly, small culverts regularly pass under roads, serving the same function as a bridge, except for smaller discharges of water. Whereas bridges and large concrete box culverts are obvious on most images, corrugated metal pipe culverts are often concealed, making it difficult for hydro-enforced DEMs to reflect all drainage features associated with roads and railroads.

1.4.2 Passive Remote Sensing Sources

Aerial photography and satellite imaging are the two most common forms of passive remote sensing.

1.4.2.1 Aerial Photography

Aerial photography uses the sun as the source of illumination. Because no energy is emitted from an aerial survey camera, aerial photography is considered to be a passive remote sensing source. It is limited by visibility, time-of-year, and time-of-day in which sun angles are optimum for aerial photography without excessive shadows. For decades, DEMs have been compiled photogrammetrically from stereoscopic aerial photography. The vertical accuracy of such DEMs is a function of the flying height and focal length of the mapping camera used.

1.4.2.2 Satellite Imagery

Satellite imagery, which is also illuminated by the sun, may be used to photogrammetrically compile DEMs and other elevation data from stereoscopic imagery. Because the vertical accuracy of such DEMs is a function of the flying height and equivalent focal length of the mapping camera, plus other error sources (For example, position and attitude errors), DEMs derived from satellite imagery are generally restricted to an accuracy of 5 meters or worse.

1.4.3 Active Remote Sensing Sources

1.4.3.1 Interferometric Synthetic Aperture Radar (IFSAR)

IFSAR is an interferometric radar system, flown aboard fixed-wing aircraft or space-based platforms, that is used to acquire 3-D coordinates of terrain and terrain features that are both manmade and naturally occurring. IFSAR systems use the synthetic aperture phase history data from two spatially separated antennae over an imaged swath that may be located to the left, right, or both sides of the imaging platform's flight path to derive accurate terrain heights. C-band and X-band IFSARs, including the Shuttle Radar Topography Mission (SRTM), are used to map the reflective surfaces of terrain features in production of Digital Surface Models (DSMs). The C-band and X-band radars penetrate the foliage to different depths based upon the frequency. Although not yet proven in practice, the new P-band IFSARs are designed to penetrate vegetation to map the bottom, bare-earth terrain features (DTMs). IFSAR systems operate both day and night and are generally "all weather" systems that penetrate cloud cover.

1.4.3.2 Light Detection and Ranging (LIDAR)

Airborne LIDAR uses an instrument, flown aboard rotary or fixed-wing aircraft, that measures the distance to a reflecting object by emitting timed pulses of laser light and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to distance. With topographic LIDAR systems, first-return LIDAR pulses are used to map the top surfaces of terrain features, i.e., to create DSMs. Last-return LIDAR pulses are used to map the bottom, bare-earth terrain features, i.e., to create Digital Terrain Models (DTMs), after post-processing to remove vegetation and other elevated features. Airborne LIDAR Bathymetry (ALB) systems use two different lasers to measure the depth beneath the water surface; however, their effectiveness is totally dependent upon the clarity of the water. LIDAR systems operate both day and night, but they do not penetrate cloud cover.

1.4.3.3 Sound Navigation and Ranging (sonar)

Sonar is an apparatus that detects the presence of, or determines the distance or direction of, an underwater object or surface by receiving and interpreting sound from the object/surface. The term is applied principally to an apparatus that itself generates the sound; the object/surface then reflects or scatters the sound back to the apparatus.

1.4.4 Mobile Survey Platforms

1.4.4.1 GPS Real Time Kinematic (RTK)

Real Time Kinematic GPS is a method of utilizing carrier phase differential GPS with on-the-fly ambiguity resolution transmitted from a base station with known coordinates to a rover receiver via a radio link**.** This technique will compute a position in real time, relative to the base station within accuracies of a few centimeters.

1.4.4.2 Ground Surveys

Static GPS or conventional surveys can also be used to survey elevations for digital elevation modeling. The most common ground surveys are cross-section surveys across stream channels, to include elevations of river bottoms below the water level.

1.5 DATA QUALITY

1.5.1 Accuracy Requirements

1.5.1.1 Vertical Accuracy

Vertical accuracy is the principal criterion in specifying the quality of digital elevation data, and vertical accuracy requirements depend upon the intended user applications (see Chapter 11, "Digital Elevation Model Technologies and Applications: The DEM Users Manual," ASPRS, 2001.) There are five principal applications where high vertical accuracy is normally required of digital elevation datasets: (1) for marine navigation and safety, (2) for stormwater and floodplain management in flat terrain, (3) for management of wetlands and other ecologically sensitive flat areas, (4) for infrastructure management of dense urban areas where planimetric maps are typically required at scales of 1 inch = 100 feet' and larger scales, and (5) for special engineering applications where elevation data of the highest accuracy are required. Whereas there is a tendency to specify the highest accuracy achievable for many other applications, users must recognize that lesser standards may suffice, especially when faced with the increased costs for higher accuracy elevation data.

The NDEP recommends that users attempt to assess vertical accuracy requirements in terms of potential harm that could be done to the public health and safety in the event that the digital elevation data fail to satisfy the specified vertical accuracy. Many states have regulations that require digital elevation data to be produced by licensed individuals to protect the public from any harm that an incompetent data producer may cause. Licensing is generally linked to experience in proving that products are delivered in accordance with the National Map Accuracy Standards, or equivalent.

It is important to specify the vertical accuracy expected for all final products being delivered. For example, when contours or gridded DEMs are specified as deliverables from photogrammetric or LIDAR-generated mass points, a TIN may first be produced from which a DEM or contours are derived. If done properly, error introduced during the TIN to contour/DEM process should be minimal; however, some degree of error will be introduced. Accuracy should not be specified and tested for the TIN with the expectation that derivatives will meet the same accuracy. Derivatives may exhibit greater error, especially when generalization or surface smoothing has been applied to the final product. Specifying accuracy of the final product(s) requires the data producer to ensure that error is kept within necessary limits during all production steps.

The vertical accuracy of elevation models is also a function of horizontal resolution. Refer to section 1.3.8.2 for an explanation of this relationship.

Information about the National Map Accuracy Standard (NMAS) and the National Standard for Spatial Data Accuracy (NSSDA) is provided in Part 5. An understanding of the basic principles of these Standards will be helpful for understanding the following guidance for determining vertical and horizontal accuracy requirements.

With the NSSDA, the $RMSE_z$ is defined in terms of feet or meters at ground scale, rather than in terms of the published map's contour interval. Because the NSSDA does not address the suitability of data for any particular product, map scale, contour interval, or other application, no error thresholds are established by the standard. However, it is often helpful to use familiar NMAS thresholds for determining reasonable NSSDA accuracy requirements for various types of terrain and relief. The $Accuracy_z$ values shown in table 2 are NSSDA equivalents to the NMAS error thresholds for common contour intervals.

Table 2 Comparison of NMAS/NSSDA Vertical Accuracy

NMAS Equivalent Contour Interval	**NMAS** VMAS 90 percent confidence level Maximum Error Tolerance	**NSSDA** $RMSE_z$	**NSSDA** $Accuracy_z$, 95 percent confidence level
1 ft	0.5 ft	0.30 ft or 9.25 cm	0.60 ft or 18.2 cm
2 ft	1 ft	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm
4 ft	2 ft	1.22 ft or 37.0 cm	2.38 ft or 72.6 cm
5 ft	2.5 ft	1.52 ft or 46.3 cm	2.98 ft or 90.8 cm
10 ft	5 ft	3.04 ft or 92.7 cm	5.96 ft or 1.816 m
20 ft	10 ft	6.08 ft or 1.853 m	11.92 ft or 3.632 m
40 ft	20 ft	12.16 ft or 3.706 m	23.83 ft or 7.264 m
80 ft	40 ft	24.32 ft or 7.412 m	47.66 ft or 14.528 m

In completing the User Requirements Menu (table 1), the required vertical accuracy should be specified in terms of $Accuracy_z$, which may be uniquely derived for a particular application or extracted from the right column of table 2 above. Testing of elevation data over various ground cover categories has revealed that magnitude and distribution of errors often vary between different cover types. For NDEP purposes, the dataset's "fundamental" vertical accuracy (accuracy required over open terrain) must be specified.

If specific accuracy is to be met within other ground cover categories, "supplemental" accuracies should be stated for individual or multiple categories. It may be preferable to specify a different vertical accuracy in forested areas, for example, than in tall grass. Supplemental accuracy requirements should be explained in attached documentation.

1.5.1.2 Horizontal Accuracy

Horizontal accuracy is another important characteristic of elevation data; however, it is largely controlled by the vertical accuracy requirement. If a very high vertical accuracy is required then it will be essential for the data producer to maintain a very high horizontal accuracy. This is because horizontal errors in elevation data normally (but not always) contribute significantly to the error detected in vertical accuracy tests.

Horizontal error is more difficult than vertical error to assess in the final elevation product. This is because the land surface often lacks distinct (well defined) topographic features necessary for such tests or because the resolution of the elevation data is too coarse for precisely locating distinct surface features. For these reasons, the NDEP does not require horizontal accuracy testing of elevation products. Instead, the NDEP requires data producers to report the expected horizontal accuracy of elevation products as determined from system studies or other methods (see section 1.5.3.4).

With the NSSDA, the $RMSE_r$ is defined in terms of feet or meters at ground scale, rather than in terms of the published map's scale. No error thresholds are established for horizontal accuracy by NSSDA. As a general guide, $Accuracy_r$ values shown in table 3 are the NSSDA equivalents to horizontal error thresholds established by NMAS for common map scales.

Table 3 is primarily relevant to photogrammetric data for which both planimetric and elevation data are compiled and for which the mapped features are visible on the imagery. However, it is also important to specify some minimum expectation of horizontal accuracy for elevation data acquired through nonphotogrammetric means. A horizontal accuracy specification requires the data producer to ensure that an appropriate technology and horizontal control structure is applied during the collection and processing of the elevation data.

Table 3 Comparison of NMAS/NSSDA Horizontal Accuracy

NMAS Map Scale	**NMAS** CMAS 90 percent confidence level Maximum Error Tolerance	**NSSDA** $RMSE_r$	**NSSDA** $Accuracy_r$ 95 percent confidence level
1" = 100' or 1:1,200	3.33 ft	2.20 ft or 67.0 cm	3.80 ft or 1.159 m
1 " = 200' or 1:2,400	6.67 ft	4.39 ft or 1.339 m	7.60 ft or 2.318 m
1" = 400' or 1:4,800	13.33 ft	8.79 ft or 2.678 m	15.21 ft or 4.635 m
1" = 500' or 1:6,000	16.67 ft	10.98 ft or 3.348 m	19.01 ft or 5.794 m
1" = 1000' or 1:12,000	33.33 ft	21.97 ft or 6.695 m	38.02 ft or 11.588 m
1" = 2000' or 1:24,000 *	40.00 ft	26.36 ft or 8.035 m	45.62 ft or 13.906 m

* The 1:24,000- and 1:25,000-scales of USGS 7.5-minute quadrangles are smaller than 1:20,000; therefore, the NMAS horizontal accuracy test for well-defined test points is based on 1/50 inch, rather than 1/30 inch for maps with scales larger than 1:20,000.

In completing the User Requirements Menu (table 1), the required horizontal accuracy should be specified in terms of $Accuracy_r$, which may be uniquely derived for a particular application or extracted from the right column of table 3 above.

1.5.2 Accuracy Assessment and Reporting

1.5.2.1 General Guidance

The NSSDA specifies that accuracy should be reported at the 95 percent confidence level for data tested by an independent source of higher accuracy for horizontal and/or vertical accuracy as:

Tested __ (meters, feet) horizontal accuracy at 95 percent confidence level

Tested __ (meters, feet) vertical accuracy at 95 percent confidence level

For NDEP purposes, the independent source of higher accuracy should be at least three times more accurate than the dataset being tested whenever possible.

The NSSDA further states that an alternative "compiled to meet" statement should be used when the guidelines for testing by an independent source of higher accuracy cannot be followed and an alternative means is used to evaluate accuracy. Accuracy should be reported at the 95 percent confidence level for data produced according to procedures that have been consistently demonstrated to achieve particular horizontal and/or vertical accuracy values as:

Compiled to meet __ (meters, feet) horizontal accuracy at 95 percent confidence level

Compiled to meet __ (meters, feet) vertical accuracy at 95 percent confidence level

For NDEP purposes, the "compiled to meet" statement should be used by data producers when no independent test results are available or can be practicably obtained. For example, vertical accuracy may be impossible to test against an independent source of higher accuracy in very remote or rugged terrain. The horizontal accuracy of elevation datasets is usually impossible to test because horizontal (planimetric) features are normally not well defined in elevation datasets.

It is important to note that the present NSSDA test for vertical and horizontal accuracy is valid only if errors for the dataset follow a normal or Gaussian distribution, i.e., one defined by a bell-shaped curve. (NSSDA modifications for testing and reporting accuracy of nonnormal error distributions are being recommended to the FGDC by the NDEP.) Whereas horizontal and vertical errors in open terrain typically have a normal distribution, vertical errors do not typically follow a normal distribution in other land cover categories, especially in dense vegetation where active and passive sensors are unable to detect the ground. For this reason, additional NDEP guidelines are provided below for reporting the vertical accuracy of digital elevation data in land cover categories other than open terrain (For example, forested areas, scrub, wheat or corn fields, tall weeds, mangrove, sawgrass, urban terrain).

1.5.2.2 Designing Accuracy Tests

The NSSDA specifies: *"If data of varying accuracies can be identified separately in a dataset, compute and report separate accuracy values."* Many factors will vary over time and space for any particular elevation production project. Major variations in certain factors may have significant influence on the resulting accuracy of the data. To derive an accuracy statistic that is meaningful and representative of the data, potential variables, such as those discussed below, should be considered during the design of the accuracy tests.

Continuity of Data Collection and Processing

Data producers have unique systems and procedures for collecting and processing elevation data. Any time multiple producers and collection systems are utilized to gather data over the same project area, the data should be tested separately for each producer or collection system. System components (equipment, procedures, software, etc.) may also vary over the life of a project. When there is reason to suspect that such changes may have a significant effect on accuracy, these variations should be tested separately.

Topographic Variation

Varying types of topography (such as mountainous, rolling, or flat terrain) within a project may affect the accuracy at which the elevation surface can be modeled. Also, for many applications, the accuracy requirement in high-relief terrain may be less than that for flat terrain. In such situations, it may be preferable to specify different accuracy requirements for the various terrain types and to design separate tests for each.

Ground Cover Variation

Studies have shown elevation error to be significantly affected by various ground cover types. Because vegetation can limit ground detection, tall dense forests and even tall grass tend to cause greater elevation errors than unobstructed (short grass or barren) terrain. Errors measured in areas of different ground cover also tend to be distributed differently from errors in unobstructed terrain. For these reasons, the NDEP requires open terrain to be tested separately from other ground cover types. Testing over any other ground cover category is required only if that category constitutes a significant portion of the project area deemed critical to the customer.

1.5.2.3 Selecting and Collecting Check Points

Check points should be well distributed throughout the dataset. The NDEP recommends the following NSSDA guidance be followed when choosing checkpoint locations:

Check points may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. When the distribution of error is likely to be nonrandom, it may be desirable to locate checkpoints to correspond to the error distribution. For a dataset covering a rectangular area that is believed to have uniform positional accuracy, check points may be distributed so that points are spaced at intervals of at least 10 percent of the diagonal distance across the dataset and at least 20 percent of the points are located in each quadrant of the dataset.

Land Cover Categories

The NSSDA states, "A minimum of 20 checkpoints shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95 percent confidence level allows one point to fail the threshold given in product specifications."

However, the NDEP recommends following the current industry standard of utilizing a minimum of 20 checkpoints (30 is preferred) in each of the major land cover categories representative of the area for which digital elevation modeling is to be performed; this helps to identify potential systematic errors in an elevation dataset. Thus if five major land cover categories are determined to be applicable, then a minimum of 100 total check points are required. The most common land cover categories are as follows:

- Open terrain (sand, rock, dirt, plowed fields, lawns, golf courses)
- Tall weeds and crops
- Brush lands and low trees
- Forested areas fully covered by trees
- Urban areas with dense man-made structures

It is up to the data producer and customer to determine the significant land cover categories to be tested. The selection and definition of land cover categories should be based on the unique mix and variations of land cover for the project site and the potential effect of each on the surface application. For some applications, distinction between grass, brush, and forest may not be sufficient. For example, where very high vertical accuracy is a must, it may be important to understand how variations in grass height and density affect the final vertical accuracy. In such situations, it may be preferable to break "grasses" into two or more categories based on species or stand characteristics.

Whether land cover categories are user defined or chosen based on existing land cover categories such as the Anderson or National Land Cover Dataset land-use and land-cover classification systems, they need to be reported in the metadata. User defined categories should be simple, descriptive, and representative of existing major land cover categories. For example, there is no Anderson Level II for lawns, but there is (11) residential, (16) mixed urban or built-up land, and (17) other urban or built-up land. There is a category for pasture, (21) cropland and pasture, but cropland normally has taller vegetation than "open terrain." (See Part 6 References, for more on Land Classification Systems.)

Checkpoints

The QC (quality control) checkpoints should be selected on flat terrain, or on uniformly sloping terrain for x-meters in all directions from each checkpoint, where "x" is the nominal spacing of the DEM or mass points evaluated. Whereas flat terrain is preferable, this is not always possible. Whenever possible, terrain slope should not be steeper than a 20 percent grade because horizontal errors will unduly influence the vertical RMSE calculations. For example, an allowable 1-meter horizontal error in a DEM could cause an apparent unallowable vertical error of 20 cm in the DEM. Furthermore, checkpoints should never be selected near severe breaks in slope (such as bridge abutments or edges of roads) where subsequent interpolation might be performed with inappropriate TIN or DEM points on the wrong sides of the breaklines.

Checkpoint surveys should be performed relative to National Spatial Reference System (NSRS) monuments of high vertical accuracy, preferably using the very same NSRS monuments used as GPS base stations for airborne GPS control of the mapping aircraft. This negates the potential that elevation differences might be attributed to inconsistent survey control.

NOAA Technical Memorandum NOS NGS-58, "Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)," November, 1997 (NOAA, 1997) are recommended to extend control from the selected NSRS monuments into the project area, using the National Geodetic Survey's latest geoid model to convert from ellipsoid heights to orthometric heights. GPS real-time-kinematic (RTK) procedures are acceptable as long as temporary benchmarks within the project area are surveyed twice with distinctly different satellite geometry to overcome the possibility of GPS multipath error. Subsequent to GPS surveys to extend control into the project area, conventional third-order surveys can be used to extend control to checkpoints that are typically located within forested areas or "urban canyons" where GPS signals would be blocked. QC surveys should be such that the checkpoint accuracy is at least three times more accurate than the dataset being evaluated. For example, if a DEM is supposed to have a vertical RMSE of 18.5-cm, equivalent to the accuracy required of 2' contours, then the checkpoints should be surveyed with procedures that would yield vertical RMSE of 6 cm or better.

In all methods of accuracy testing and reporting, there is a presumption that the checkpoint surveys are error free and that discrepancies are attributable to the remote sensing technology assumed to have lower accuracy. This is especially true when the checkpoint surveys are performed with technology and procedures that should yield accuracies at least three times greater than the expected accuracy of the remote sensing data being tested. However, checkpoint surveys are not always error free, and care must be taken to ensure that all survey errors and blunders are identified. When discrepancies do appear, resurveying questionable checkpoints themselves, or asking for the original checkpoint survey data to be reviewed are ways to challenge the accuracy, or inaccuracy, of the checkpoints. Because of potential challenges to the surveyed checkpoints, it is recommended that each checkpoint be marked with a recoverable item, such as a 60d nail and an adjoining flagged stake, to assist in recovery of the checkpoints for resurveys.

1.5.2.4 Deriving Dataset Elevations for Checkpoints

Once checkpoints are collected and checked for blunders, elevations corresponding to each checkpoint must be derived from each dataset to be tested. Exact procedures for obtaining these elevations will vary depending on the elevation data model and on software tools available for the test.

Whereas checkpoints may be considered to be well-defined and recoverable, mass points, TIN/DEM points, and contours are not. Because digital elevation data do not contain well-defined points, it is nearly impossible to test exactly the same points as in a DEM or TIN dataset. Therefore, it is usually necessary to interpolate an elevation from the surface model at the horizontal (x, y) location of each checkpoint.

TIN Interpolation

When mass points are specified as a deliverable, a TIN derived from the mass points provides a surface from which elevations can be directly interpolated at the horizontal location of each checkpoint. A number of commercial GIS packages have commands (such as ArcInfo TINSPOT) that perform this interpolation automatically for a list of checkpoints.

DEM Interpolation

When a gridded DEM is specified as a deliverable, it must be tested to ensure it meets required accuracies even when a TIN (tested to meet accuracy) is used as the DEM source. This is because generalization or smoothing processes employed during DEM interpolation may degrade the elevation surface. Some technologies such as IFSAR and image correlation directly produce a gridded elevation model. If a gridded DEM is to be tested, surface elevations at the checkpoint locations can be interpolated using 4-neighbor bilinear interpolation such as that used in the ArcInfo Latticespot command.

Contour Interpolation

Contours may be directly collected from stereoscopic source by a compiler or may be derived from a TIN or DEM. The contours should be tested when specified as a deliverable whether they were directly compiled or derived from another data model, even if the source model meets required accuracies. This is because the accuracy of any derived product can be degraded by interpolation, generalization, or smoothing.

Contour tests can be performed two ways. One method consists of plotting checkpoint locations in relationship with surrounding contours and mentally interpolating an elevation for that checkpoint from surrounding contours. Another method requires the contours to be converted to a TIN, from which elevations can be automatically interpreted with software. The TIN method is somewhat risky because TINing software cannot apply the rationale that may be required of the human during interpolation. Therefore, the TINing process may introduce additional error into the interpolated elevations. However, if the TIN test meets accuracy, one can be fairly confident that the contours meet accuracy. If the TIN accuracy fails, it may be necessary to perform the mental interpolation and retest.

1.5.2.5 Computing Errors

The "difference" or error for each checkpoint is computed by subtracting the surveyed elevation of the checkpoint from the dataset elevation interpolated at the x/y coordinate of the checkpoint. Thus, if the difference or error is a positive number, the evaluated dataset elevation is higher than true ground in the vicinity of the checkpoint, and if the difference is a negative number, the evaluated dataset elevation is lower.

For check point$_i$, the vertical error$_i$ $= (z_{data\ i} - z_{check\ i})$,

Where:

$z_{data\ i}$ is the vertical coordinate of the ith check point in the dataset
$z_{check\ i}$ is the vertical coordinate of the ith check point in the independent source of higher accuracy
i is an integer from 1 to n; n = the number of points being checked

1.5.2.6 Analyzing Errors

Blunders, Systematic Error, and Random Error

The "errors" measured in accuracy calculations, in theory, pertain only to random errors, produced by irregular causes whose effects upon individual observations are governed by no known law that connects them with circumstances and so cannot be corrected by use of standardized adjustments. Random errors typically follow a normal distribution. Systematic errors follow some fixed pattern and are introduced by data collection procedures and systems. Systematic errors may occur as vertical elevation shifts across a portion or all of a dataset. These can be identified through spatial analysis of error magnitude and direction or by analyzing the mean error for the dataset. Systematic errors may also be identified as large deviations from the true elevations caused by misinterpretations of terrain surfaces due to trees, buildings, and shadows, fictitious ridges, tops, benches, and striations. A systematic error is error is predictable in theory and is, therefore, not random. Where possible, systematic errors should be identified and eliminated from a set of observations prior to accuracy calculations.

A blunder is an error of major proportion, normally identified and removed during editing or QC processing. A potential blunder may be identified as any error greater than three times the standard deviation (3 sigma) of the error. Errors greater than 3 sigma should be analyzed to determine the source of the blunder and to ensure that the blunder is not indicative of some unacceptable source of systematic error. Checkpoints with large error should not simply be thrown out of the test sample without investigation; they may actually be representative of some error characteristic remaining in the elevation surface and should be addressed in the metadata.

It is generally accepted that errors in open terrain, whether from photogrammetry, LIDAR or IFSAR, represent random errors in the sensor system, whereas errors in vegetated areas may include systematic errors. For example, systematic inability to penetrate dense vegetation, and/or systematic deficiencies in procedures used to generate bare-earth elevation datasets. A single large error (outlier) in a forested area, for example, can totally skew RMSE calculations of a large population of checkpoints that otherwise satisfy the accuracy criteria.

1.5.3 Calculating and Reporting Vertical Accuracy – NDEP Requirements

1.5.3.1 Fundamental Accuracy

The ***fundamental vertical accuracy*** of a dataset must be determined with check points located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. The fundamental accuracy is the value by which vertical accuracy can be equitably assessed and compared among datasets. *Fundamental accuracy is calculated at the 95-percent confidence level as a function of vertical RMSE.*

1.5.3.2 Supplemental and Consolidated Vertical Accuracies

In addition to the fundamental accuracy, ***supplemental or consolidated accuracy*** *values* may be calculated for other ground cover categories or for combinations of ground cover categories. Because elevation errors often vary with the height and density of ground cover, a normal distribution of error cannot be assumed and, therefore, RMSE cannot be used to calculate the 95-percent accuracy value. *Consequently a nonparametric testing method (95th Percentile) is employed for supplemental and consolidated accuracy tests.*

95th Percentile

For supplemental and consolidated accuracy tests, the 95th percentile method shall be employed to determine accuracy. The 95th percentile method may be used regardless of whether or not the errors follow a normal distribution and whether or not errors qualify as outliers. Computed by a simple spreadsheet command, a "percentile" is the interpolated absolute value in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. The 95th percentile indicates that 95 percent of the errors in the dataset will have absolute values of equal or lesser value and 5 percent of the errors will be of larger value. With this method, $Accuracy_z$ is directly equated to the 95th percentile, where 95 percent of the errors have absolute values that are equal to or smaller than the specified amount.

Prior to calculating the data accuracy, these steps should be taken:

- Separate checkpoint datasets produced according to important variations in expected error (section 1.5.2.2)
- Edited collected checkpoints to minimize errors (section 1.5.2.3)
- Interpolate elevation surface for each checkpoint location (section 1.5.2.4)
- Identify and eliminate systematic errors and blunders (sections 1.5.2.5 and 1.5.2.6)

Once these steps are completed, the fundamental vertical accuracy must be calculated. If additional land cover categories are to be tested, supplemental and/or consolidated accuracies may also be computed.

Fundamental Vertical Accuracy Test

Using check points in open terrain only:

1. Compute the vertical $RMSE_z = sqrt[\Sigma(z_{data\ i} - z_{check\ i})^2/n]$
2. Compute $Accuracy_z = 1.9600 * RMSE_z$ = vertical accuracy at 95 percent confidence level.

3. Report $Accuracy_z$ as "**Tested ______(meters, feet) fundamental vertical accuracy at 95 percent confidence level in open terrain using RMSEz x 1.9600.**"

The following accuracy statements are optional. When used they must be accompanied by a *fundamental* vertical accuracy statement. The only possible exception to this rule is the rare situation where accessible pockets of open terrain (road clearings, stream beds, meadows, or isolated areas of exposed earth) do not exist in sufficient quantity for collecting the minimum test points. Only in this instance may supplemental or consolidated accuracies be reported without an accompanying fundamental accuracy. However, this situation must be explained in the metadata. Most likely, when producing an elevation surface where little or no accessible open-terrain exists, the data producer will employ a collection system that has been previously tested to meet certain accuracies and a "compiled to meet" statement would be used in lieu of a "tested to" statement.

Supplemental Vertical Accuracy Tests

When testing ground cover categories or combinations of categories excluding open terrain:

1. Compute 95^{th} percentile error (described above) for each category (or combination of categories).
2. Report "**Tested ______(meters, feet) supplemental vertical accuracy at 95^{th} percentile in (specify land cover category or categories)**"
3. In the metadata, document the errors larger than the 95^{th} percentile. For a small number of errors above the 95^{th} percentile, report x/y coordinates and z-error for each QC check point error larger than the 95^{th} percentile. For a large number of errors above the 95^{th} percentile, report only the quantity and range of values.

Consolidated Vertical Accuracy Tests

When 40 or more check points are consolidated for two or more of the major land cover categories, representing both the open terrain and other land cover categories (for example, forested), a *consolidated vertical accuracy* assessment may be reported as follows:

1. Compute 95^{th} percentile error (described above) for open terrain and other categories combined.
2. Report "**Tested ______(meters, feet) consolidated vertical accuracy at 95^{th} percentile in: open terrain, (specify all other categories tested)**"
3. In the metadata, document the errors larger than the 95^{th} percentile. For a small number of errors above the 95^{th} percentile, report x/y coordinates and z-error for each QC check point error larger than the 95^{th} percentile. For a large number of errors above the 95^{th} percentile, report only the quantity and range of values.

If the fundamental accuracy test fails to meet the prescribed accuracy, there is a serious problem with the control, collection system, or processing system or the achievable accuracy of the production system has been overstated. If a systematic problem can be identified, it should be corrected, if possible, and the data should be retested.

1.5.3.3 Reporting Vertical Accuracy of Untested Data – NDEP Requirements

Use the 'compiled to meet' statement below when the above guidelines for testing by an independent source of higher accuracy cannot be followed and an alternative means is used to evaluate accuracy. Report accuracy at the 95 percent confidence level for data produced according to procedures that have been demonstrated to produce data with particular vertical accuracy values as:

> ***Compiled to meet ___ (meters, feet) fundamental vertical accuracy at 95 percent confidence level in open terrain***

The following accuracy statements are optional. When used they must be accompanied by a *fundamental* vertical accuracy statement.

> For ground cover categories other than open terrain, report:
>
> ***Compiled to meet ___ (meters, feet) supplemental vertical accuracy at 95th percentile in (specify land cover category or categories***)
>
> For all land cover categories combined, report:
>
> ***Compiled to meet ___ (meters, feet) consolidated vertical accuracy at 95th percentile in: open terrain, (list all other relevant categories)***

1.5.3.4 Testing and Reporting Horizontal Accuracy – NDEP requirements

The NDEP does not require independent testing of horizontal accuracy for elevation products. When the lack of distinct surface features makes horizontal accuracy testing of mass points, TINs, or DEMs difficult or impossible, the data producer should specify horizontal accuracy using the following statement:

> ***Compiled to meet ___ (meters, feet) horizontal accuracy at 95 percent confidence level***

The expected accuracy value used for this statement must be equivalent to the horizontal accuracy at the 95 percent confidence level = $Accuracy_r$ = $RMSE_r$ x 1.7308. This accuracy statement would be appropriate for the following situation. LIDAR vendors normally advertise that their systems deliver data with an $RMSE_r$ of approximately 1 meter. Such 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 surrounding these buildings) and compared with LIDAR calibration flights flown over the calibration area from multiple directions. The horizontal accuracy with which these building breaklines can be determined provides a good estimate of the achievable horizontal accuracy of LIDAR datasets obtained under similar conditions.

For very high-resolution elevation data where well-defined surface features such as narrow stream junctions, small mounds, or depressions can be identified, it may be possible and desirable to actually test and report the resulting horizontal accuracy. It may also be possible to independently test the horizontal accuracy of LIDAR and IFSAR elevation surfaces if the corresponding intensity data is earth-referenced by the same process used for the elevation data, and if the intensity values enable a sufficient number of clearly defined planimetric features to be located. For example, white numbers and lines on airport runways and painted stripes on roads are often visible on LIDAR intensity images. When this occurs, it is possible to survey those features on the ground and compare their horizontal coordinates with those derived from the LIDAR intensity images. In this way, LIDAR intensity images become comparable to photogrammetric images for which $RMSE_r$ can be computed in accordance with standard NSSDA testing procedures. Results of horizontal accuracy tests should be reported using the following statement:

Tested ___ (meters, feet) horizontal accuracy at 95 percent confidence level.

1.5.3.5 Accuracy Assessment Summary

Providers of digital elevation data use a variety of methods to control the accuracy of their products. Photogrammetrists use survey control points and aerotriangulation to control and evaluate the accuracy of their data. LIDAR and IFSAR providers may collect hundreds of static or kinematic control points for internal quality control and to adjust their datasets to these control points. To the degree that such control points are used in a fashion similar to control for aerotriangulation, for which the LIDAR or IFSAR datasets are adjusted to better fit such control points, then the data providers may use the "compiled to meet" accuracy statements listed above. With mature technologies such as photogrammetry, users generally accept "compiled to meet" accuracy statements without independent accuracy testing. However, with developing technologies such as LIDAR or IFSAR, users often require independent accuracy tests for which accuracy reporting is more complex, especially when errors include "outliers" or do not follow a normal distribution as required for the use of RMSE in accuracy assessments. Because of these complexities, the NDEP mandates the "truth in advertising" approach, described above, that reports vertical accuracies in open terrain separately from other land cover categories, and that documents the size of the errors larger than the 95th percentile in the metadata.

1.5.3.6 Relative Vertical Accuracy

The accuracy measurement discussed in this chapter refers to absolute vertical accuracy, which accounts for all effects of systematic and random errors. For some applications of digital elevation data, the point-to-point (or relative) vertical accuracy is more important than the absolute vertical accuracy. Relative vertical accuracy is controlled by the random errors in a dataset. The relative vertical accuracy of a dataset is especially important for derivative products that make use of the local differences among adjacent elevation values, such as slope and aspect calculations. Because relative vertical accuracy may be difficult to measure unless a very dense set of reference points is available, this NDEP guideline does not prescribe an approach for its measurement. If a specific level of relative vertical accuracy is a stringent requirement for a given project, then the plan for collection of reference points for validation should account for that. Namely, reference points should be collected at the top and bottom of uniform slopes. In this case, one method of measuring the relative vertical accuracy is to compare the difference between the elevations at the top and bottom of the slope as represented in the elevation model vs. the true surface (from the reference points). Figure 5 shows a profile view of a uniform slope with the true and model points depicted, and how the values may be used to express relative vertical accuracy. In many cases, the relative vertical accuracy will be much better than the absolute vertical accuracy, thus the importance of thoroughly measuring and reporting the absolute accuracy, as described in this chapter, so the data users can have an idea of what relative accuracy to expect.

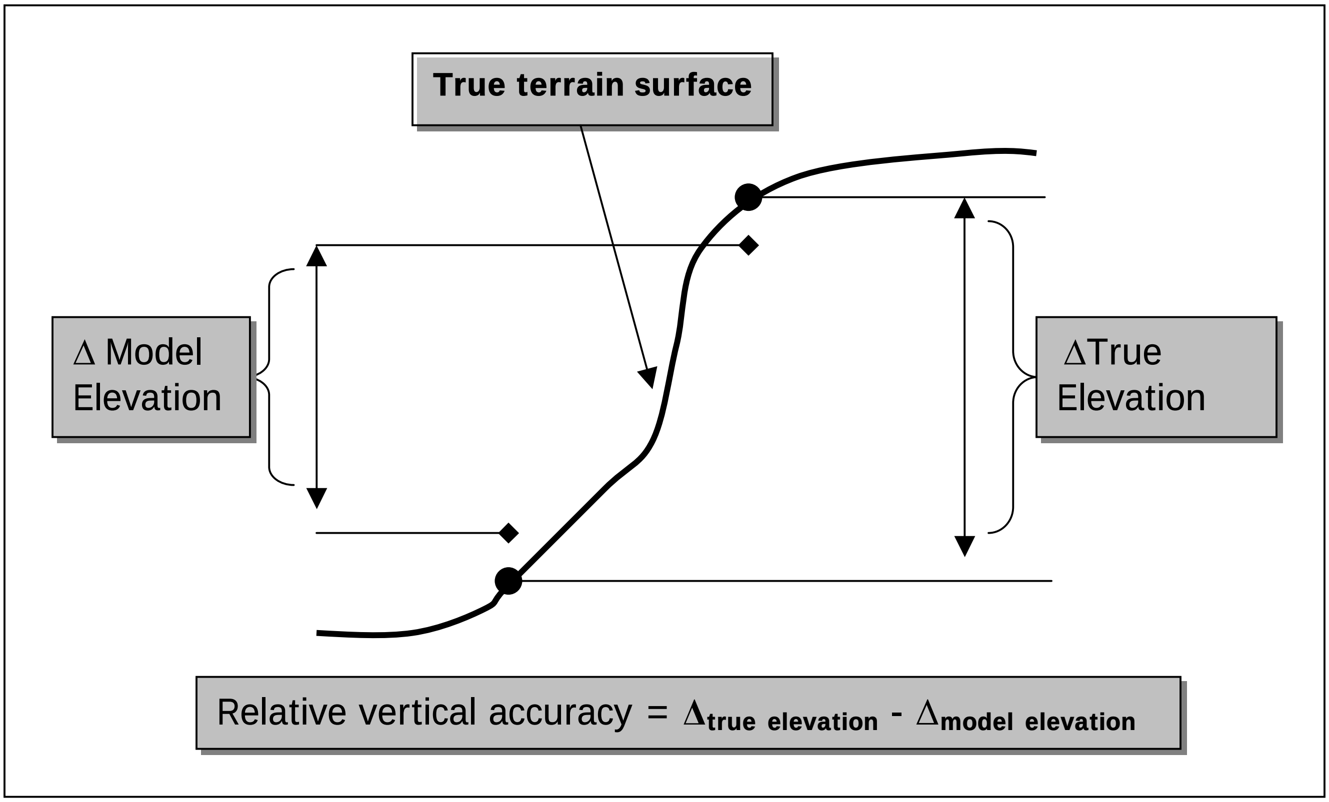

Figure 5 Relative Vertical Accuracy

1.5.4 Surface Treatment Factors

The surface types presented in section 1.2.1, although useful for general discussion, define only broad categorizations of elevation surface characteristics. Merely specifying a “bare-earth” or “top surface” elevation model does not sufficiently define how all terrain features are to be represented in the final surface. For example, specifying a bare-earth surface usually implies that elevations on buildings and vegetation should be removed but it does not necessarily imply that overpasses and bridges should be removed from the surface.

The intended application of an elevation model typically dictates the particular terrain features to be represented and how those features are to be depicted. Conventions for depicting various features have changed over time. Because of the increasing variety of applications for elevation models, the trend is moving away from strict standardization of how features should be depicted and is moving toward customization for the primary data application.

The customer should always provide explicit instructions for representation of the features discussed below or any other terrain feature that might require special treatment. Data producers should document special feature treatments in the metadata.

1.5.4.1 Hydrography

A form of hydro-enforcement is discussed in sections 1.4.1.2 and 1.4.1.3**.** Hydro-enforcement is also explained in the introductory chapter of ASPRS, 2001. Hydro-enforcement, performed to depict the flow of water in digital elevation models, is required when remote sensing systems capture man-made structures as well as natural irregularities in the terrain, including shorelines that appear to undulate up and down. There are different forms of hydro-enforcement that may include any or all of the following: leveling of ponds, lakes and reservoirs that ought to be flat instead of undulating; rivers, streams and narrow drains that ought to depict the downward flow of water instead of undulating up and down; manmade structures that actually impede the flow of water (in the case of buildings) as opposed to other structures that only appear to impede the flow of water (in the case of bridges and overpasses); and sinkholes and depressions that actually exist as opposed to artificial puddles that fail to depict natural outlet drains or culverts. Each of these topics is further explained in the following sections.

a. Water bodies

Water body areas are naturally occurring areas of constant elevation, provided that currents and other physical forces do not significantly alter the water surface. Oceans, bays, or estuaries at mean sea level were traditionally assigned an elevation value of zero, although more recent datums (such as NAVD 88) properly account for the physical situation that mean sea level actually equates to different elevations along different coastlines because of variations in ocean topography, currents, and winds. Ponds, lakes and reservoirs are assigned their known or estimated elevations, and their shorelines may be treated as breaklines with constant elevation. The horizontal position and shape of water body shorelines is normally determined from digital orthophotos or other georeferenced image source.

b. Rivers and Streams

Rivers and streams are also naturally occurring but normally have variable elevations to depict the downward flow of water. These features are generally wide enough that both shorelines can be represented in the elevation model. The horizontal position and shape of the double shorelines is normally determined from digital orthophotos or other georeferenced image source. These shorelines are also treated as breaklines in one of several ways.

- When contour lines exist, polygons can be established, bounded by the dual shorelines and upstream and downstream crossing contours, with a uniform elevation assigned to the entire polygon to match that of the lower crossing contour. This is a simple approach but causes the drainage polygons to be "stair-stepped" according to the contour interval.

- When contour lines exist, the crossing contours can be used to establish the elevations at discrete points along the breaklines that delineate the double shorelines. Elevations are then linearly interpolated for each shoreline vertex between the discrete points. These shoreline breaklines are now 3-D breaklines in which the elevation gradually decreases from the upstream contour elevation to the downstream contour elevation. This is a form of hydro-enforcement. The elevations of midstream points are then interpolated from the surrounding shoreline elevations.

- When contour lines do not exist, the horizontal position and shape of the double shorelines may still be determined from digital orthophotos or other georeferenced image source. Then, alternative methods may be used to estimate the water elevations at various locations along the stream for creating sloping 3-D shorelines. With LIDAR, for example, there are normally some pulses that reflect off of water ripples. When there are a dozen or more returns in water areas that depict consistent elevations, these values may be used to estimate the water elevation at those locations. Alternatively, the lowest elevations along stream banks at selected intervals or locations can be used for the same purpose, and then interpolated to depict continuously sloping shorelines as 3-D breaklines.

c. Narrow drains
When continuous downstream drainage is desirable, narrow drainage channels may be enforced by a single 3D breakline. Breakline enforcement in this situation ensures that no false dams or puddles are represented in the model. Such erroneous features commonly occur in elevation surfaces captured or represented by randomly or uniformly spaced discrete points. A drainage breakline, captured as described under Rivers and Streams, may be used to represent the actual drain channel in a TIN or may be used to assign a lowest local-area elevation to the nearest point in an elevation grid.

1.5.4.2 Man-made Structures

a. Buildings
For most applications, a bare earth DEM means that elevation points on buildings (and trees) are removed, basements are neglected, and the terrain where the building exists is smoothed and interpolated from ground elevations surrounding the buildings. However, for hydraulic modeling of floodplains, elevations of buildings may be retained to show that buildings occupy spaces where floodwaters flow and they also impede the natural flow of flood waters.

b. Bridges
Because most aerial and satellite sensors detect the first reflective surface, bridge surfaces and supporting structures are represented in the original source data. When the surface is intended primarily for road network modeling, such representation may be desirable. If so, the desired bridge structure (for example, road surface without superstructure) should be specifically requested for the elevation model. If, however, water modeling is the primary purpose for the data, it may be preferable to request that elevations falling on bridge surfaces be edited out and replaced with a logical stream-flow surface.

c. Overpasses
Overpasses present the same issues as bridges. Desired treatment of overpasses should be specifically documented.

d. Culverts
Drainage through small culverts is typically not depicted in elevation models. Whereas bridges and large concrete box culverts are obvious on most images, metal pipe culverts are often concealed, making it difficult for hydro-enforced DEMs to reflect all drainage features associated with roads and railroads. For some large-scale drainage applications it may be desirable to model the drainage surface of the culvert, but usually the cost of collecting necessary information on culverts significantly outweighs the benefits of this type of hydrographic enforcement. Large concrete culverts may be more easily identified from project photography allowing the underlying drain surface to be affordably modeled.

1.5.4.3 Special Earthen Features

Special earthen features are natural features of the earth that require special consideration.

a. Sinkholes
Sinkholes should be verified whenever possible and should be depicted as depressions in the elevation model.

b. Natural bridges
Typically, the top surface of a natural bridge is represented in the model. When water flow modeling is the primary application for an elevation surface, it may be preferable to treat natural bridges similar to man-made bridges and depict the stream surface below the bridge.

1.5.4.4 Artifacts

An important quality factor for a DEM is its "cleanness" from artifacts. Artifacts are detectable surface remnants of buildings, trees, towers, telephone poles or other elevated features in a bare-earth elevation model. They may also be detectable artificial anomalies that are introduced to a surface model via system-specific collection or processing techniques (for example, corn-row effects of profile collection, star and ramp effects from multidirectional contour interpolation, edge-join offsets, or detectable triangular facets caused when vegetation canopies are weeded from LIDAR data.)

The majority of artifacts are normally removed by automated post-processing. However, the final cleaning of the last 10 percent of the artifacts may take 90 percent of the post-processing budget. Because of costs, users sometimes accept a moderate amount of artifacts, whereas others find artifacts totally unacceptable. Cleanness can be specified as a percentage of the total area. However, quantifying and testing to an acceptable threshold of artifacts is a difficult, subjective, and time-consuming process. Because artifacts are so difficult to quantify, it is best if the user discusses with the data provider the types of artifacts, which artifacts are acceptable (if any), and which artifacts are unacceptable and must be eliminated.

1.5.4.5. Special Surfaces

a. No-Data Areas: Intentional/Unintentional
Specific information needs to be provided by the data producer that differentiates whether the lack of data is intentional or unintentional. Some indication must be provided outside of the data model (for example in the project metadata or as a polygon) that describes where these areas are in the elevation deliverable. Examples of intentional No-Data Areas would be areas outside the project area, large bodies of water on DEM tiles that are deliberately not collected to lower production costs or areas of sensitive information such as military bases. Unintentional No-Data Areas are those where high winds, pilot or navigation errors cause gaps between adjoining strips. For both intentional and unintentional No-Data Areas a unique value, such as –32768, may be used to flag the areas.

b. Suspect areas
Areas of elevations for which there is a relatively low degree of confidence. They are areas where the producer questions whether the elevations compiled or sensed represent the bare earth. Some indication must be provided outside of the data model (for example in the project metadata or as a polygon) that describes where these areas are in the elevation deliverable.

.

1.6 DATUMS/GEOID

1.6.1 Horizontal Datum

The North American Datum of 1983 (NAD 83) is the official horizontal datum of the United States and should be the default horizontal datum for all geospatial datasets of the United States. NAD 83 is based on the Geodetic Reference System of 1980 (GRS 80) ellipsoid. When NAD 83 was first introduced, it was intended to be nearly identical to the World Geodetic System 1984 (WGS 84). However, recent evidence suggests that NAD 83 is nongeocentric by about 2.25 meters, while the latest version of WGS 84 is geocentric to a few centimeters. The official horizontal datum over the United States for military applications uses the WGS 84 ellipsoid.

1.6.2 Vertical Datum

The North American Vertical Datum of 1988 (NAVD 88) is the official vertical datum of the United States and should be the default vertical datum for all elevation datasets of the United States.

1.6.3 Geoid Model

To accurately convert elevations from GPS surveys into traditional orthometric heights, it is necessary to apply geoid height corrections as depicted in the latest geoid model of the area of interest. The National Geodetic Survey (NGS) updates the geoid model on an ad-hoc 3-year cycle, For example, GEOID93, GEOID96, GEOID99, etc. It is important that the latest geoid model be used for all surveys that involve GPS, and it is also important that the metadata for any digital elevation dataset include the geoid model that was used. For example, now that GEOID03 is available, it is important to know whether GEOID03, GEOID99, or GEOID96 corrections were applied to an existing dataset to improve the accuracy of an old survey. However, it is critical to remember that overlapping geoid models (such as GEOID99 for the USA and GSD95 for Canada) generally disagree with one another, causing step-functions in any DEM that crosses the border. The military uses the WGS 84 geoid for all applications globally. Therefore, this system has no discontinuities at country borders or boundaries.

See section 1.2.2 for more information about orthometric, ellipsoid, and geoid heights.

1.7 COORDINATE SYSTEMS AND UNITS

1.7.1 Coordinate System

In the most common coordinate systems, the 3-D coordinates of any point are defined by a pair of horizontal coordinates plus a z-value that normally equates to its orthometric height. It is important that the horizontal coordinate system be specified clearly to avoid confusion. The most widely used coordinate systems are discussed below.

1.7.1.1 UTM Coordinates

Universal Transverse Mercator (UTM) coordinates are normally preferred by Federal agencies responsible for large mapping programs nationwide. UTM is a planar coordinate system based on a uniform (and universal) Transverse Mercator grid that is the same for 60 UTM zones, each 6 degrees in longitude, worldwide. UTM coordinates are metric. Units should always be specified to include the number of decimal places used for meters. It is possible to specify UTM coordinates in meters and elevations in feet. X-coordinates are called "eastings" and Y-coordinates are called "northings." UTM scale factor errors are between 0.9996 and 1.0004, i.e., four parts in 10,000. Scale factor errors are inevitable when warping a nearly spherical surface to map it on a gridded piece of paper configured as a plane, cylinder or cone.

1.7.1.2 State Plane Coordinates

Each state has a unique State Plane Coordinate System (SPCS) that is tailored to the size and shape of the State so that scale factor errors are no larger than 1 part in 10,000, i.e., scale factor errors are between 0.9999 and 1.0001. States longer in the north-south direction utilize one or more Transverse Mercator grid zones for their States. States longer in the east-west direction utilize one or more Lambert Conformal Conic grid zones. Some States (for example, Florida and New York) use both Transverse Mercator and Lambert Conformal Conic zones, and Alaska also uses an oblique projection for one zone. Some States (e.g., Montana) chose to use only a single SPCS zone for convenience purposes, accepting scale factor errors larger than 1 part in 10,000. State plane coordinates are often expressed in U.S. survey feet, although some states use metric units. Units should always be specified, to include the number of decimal places used for either feet or meters. As with UTM, State Plane X-coordinates are called "eastings" and Y-coordinates are called "northings."

1.7.1.3 Geographic Coordinates

Horizontal coordinates can always be specified in terms of geographic coordinates, i.e., longitude and latitude instead of eastings and northings. There are no scale factor errors associated with geographic coordinates.

1.7.2 Grid Coordinate Structure Geometry

1.7.2.1 Orthogonal Grid Structure

As shown in figures 1 and 2, DEMs may be produced with a uniform grid spacing ($\Delta x = \Delta y$) of 30 meters, 10 meters, or 5 meters, for example, where easting and northing coordinates of DEM posts are typically specified by uniform x/y grid spacing based on a SPCS grid, a UTM grid, or an Albers equal area grid. Because such DEM points are equally spaced in x and y directions (eastings and northings), they can present edge-join difficulties at tile boundaries where convergence of the meridians cause rows to shorten in length at higher latitudes.

1.7.2.2 Arc-Second Structure

As shown in figure 2, DEMs may be produced with a consistent grid spacing of 1-arc-second (approximately 30 meters at the Equator), 1/3-arc-second (approximately 10 meters at the Equator), or 1/9-arc-second (approximately 3.3 meters at the Equator), for example, where Δx and Δy spacings between DEM posts are specified by consistent incremental changes in longitude and latitude. Because of convergence of the meridians, such DEM points will gradually come closer together at higher latitudes and physical, on-the-ground, post spacing in the east-west direction will be different than physical, on-the-ground post spacing in the north-south direction. A major advantage of the arc-second structure is that DEM tile edge-join difficulties are minimized or even eliminated.

1.8 DATA FORMAT

The following data formats are explained in more detail in Chapter 13 of ASPRS, 2001.

1.8.1 Digital Contour Lines and Breaklines

Digital contours and breaklines are vector datasets that are typically produced in any of the following file formats: .DGN, .DO (DLG Optional), .DWG, .DXF, .E00, .MIF/.MID, .SHP, SDTS, or VPF. Other vector file formats may be specified if required.

1.8.2 Mass Points and TINs

Mass points are typically produced as ASCII x/y/z files, ASCII files with additional attribute data, LAS, or BIN format. They may be converted and stored in a TIN format, but TIN files are much larger than the mass point files from which they are derived because the TIN structure has to accommodate the topological data structure that exists between each TIN triangle and its adjoining neighboring triangles. For this reason, users often store the x/y/z point data files in ASCII format, and then reconstruct TINs when needed.

1.8.3 Grid Elevations

Grid elevations are typically produced in any of the following file formats: ASCII x/y/z, .BIL, .BIP, .DEM (USGS standard), DTED (NGA standard), ESRI Float Grid, ESRI Integer Grid, GeoTIFF, or .RLE. Other grid elevation formats may be specified if required.

1.9 FILE SIZE AND EXTENT

1.9.1 File Size

A range of acceptable file sizes should be specified. Factors to consider include: desktop computing power and capacity, storage/transfer media capacities, file transfer rates, and file display, manipulation, and maintenance efficiency.

1.9.2 File Extent

The file extent should also be specified. For small projects, the entire project extent may fit well into one manageable file. For large projects, the project area must be broken into multiple files to make the datasets manageable. File boundaries may be rectangular – based on consistent intervals of feet, meters, or degrees (see figures 1-3), or nonrectangular – based on a string of x/y coordinates. Examples of nonrectangular boundaries are watersheds, counties, or reservations. Indicate if the data requestor will provide the coordinates for a nonrectangular boundary, or if they are to be obtained from a particular source by the data producer. If a buffer area surrounding the defined extent is desirable (for example, to ensure that a watershed is completely covered) the width of the buffer should be specified.

Final file size will be dictated by the density of the data and by the specified file extent. The data producer can provide an estimate of file size for a particular product with the desired file extent. If the expected file size for a desired file extent is too large, the data provider can suggest alternative file extents or possibilities for sub-sampling the data to reduce volume.

PART 2: ELEVATION PRODUCT DESCRIPTIONS

Part 2: Elevation Product Descriptions lists the elevation products and product specifications of the individual NDEP members, and provides a brief description of each. Links to product specifications and/or authoritative resources are provided. Ultimately, Part 2 will consist of lists of Federal elevation products that comply with this guideline.

The *NDEP Elevation Guidelines* were designed to assure new elevation products of the NDEP consortium comply with a minimal set of technical requirements and as a gauge against which all the existing elevation products of the NDEP consortium would be measured. This means, while individual members may create elevation products to meet their agency's specific requirements and may differ from these guidelines, they must also be able to provide those products to other users that conform to these guidelines.

The NDEP Technical Subcommittee is confident that the guidelines in this document assure most existing elevation data can easily be brought into conformance with them and that the member agencies will see the advantages in doing so.

2.1 FEMA

FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners* defines technical requirements and product specifications for flood hazard maps and related National Flood Insurance Program (NFIP) products.
http://www.fema.gov/mit/tsd/dl_cgs.htm Appendix A: Aerial Mapping and Surveying contains specifications for data models and surfaces.

2.2 NASA

SRTM DEM

The SRTM radar contained two types of antenna panels, C-band and X-band. The near-global topographic maps are made from the C-band radar data and are processed at the Jet Propulsion Laboratory. The X-band radar data is processed and distributed by the German Aerospace Center, DLR, and used to create higher resolution DEMs but not with global coverage. SRTM is a product of a joint NASA-NGA effort. Under agreement with NASA and NGA, the USGS EROS Data Center distributes and archives SRTM data in accordance with a joint partnership Memorandum of Understanding between NASA and NGA.

2.3 NGA

Digital Terrain Elevation Data (DTED ®)

SRTM DEM (see above)

2.4 NOAA

NOAA offers a variety of digital terrain and bathymetric data:
http://www.ngdc.noaa.gov/mgg/bathymetry/relief.html

ETOPO5

http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML

2.5 USGS

Standards for USGS Elevation Products
http://rockyweb.cr.usgs.gov/nmpstds/demstds.html

National Elevation Dataset

http://ned.usgs.gov

The National Elevation Dataset (NED) is a seamless raster product derived primarily from USGS 10- and 30-meter Digital Elevation Models (DEMs), along with higher resolution data where available. NED data for the conterminous United States, Hawaii, and Puerto Rico are expressed in geographic coordinates (latitude/longitude). It is horizontally referenced to the North American Datum of 1983 (NAD83) and vertically referenced to the North American Vertical Datum of 1988 (NAVD88). The resolution is one arc-second (approximately 30 meters). NED data for Alaska is expressed in geographic coordinates (latitude/longitude). It is horizontally referenced to the North American Datum of 1927 (NAD27) and vertically referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The resolution is two arc-seconds (approximately 60 meters).

USGS 7.5-minute DEM

Coverage is provided in 7.5 x 7.5 minute blocks corresponding to the standard USGS 7.5 minute map series quadrangle. The data consists of a regular array of elevations referenced horizontally in UTM with the reference datum being either North American Datum of 1927 (NAD 27) or North American Datum of 1983 (NAD 83). Elevations are either meters or feet referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). The average file size of a 30-meter DEM is 1.1 megabytes and 9.9 megabytes for a 10-meter DEM. They are available in native and Spatial Data Transfer Standard (SDTS) format. Native format is distributed on CD-ROM, 8-mm tape, and File Transfer Protocol (FTP). SDTS is distributed via FTP download.

USGS 7.5-minute Alaska DEM

USGS 7.5-minute Alaska DEMs correspond to the USGS 1:24,000- and 1:25,000-scale topographic map series for Alaska. The exact area of coverage will vary according to latitude. They are expressed in geographic coordinates (latitude/longitude) and are referenced to either NAD27 or NAD83. Grid spacing is 1 arc-second of latitude by 2 arc-seconds of longitude. Files are available in native format and are distributed on CD-ROM, 8-mm tape, and FTP.

USGS 15-minute Alaska DEM

15-Minute Alaska DEMs correspond to the USGS 1:63,360-scale topographic map series for Alaska. The exact area of coverage will vary according to latitude. They are expressed in geographic coordinates (latitude/longitude) and are referenced to either NAD27 or NAD83. Grid spacing is 2 arc-seconds of latitude by 3 arc-seconds of longitude. Files are available in native format and are distributed on CD-ROM, 8-mm tape, and FTP.

2-Arc-Second DEM (USGS 30-minute DEM)

2 x 2 arc-second data spacing referenced horizontally on the geographic coordinate system (latitude / longitude) of the North American Datum of 1927 (NAD 27) or the North American Datum of 1983 (NAD 83). Elevations are in meters or feet referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Data is delivered in units of coverage of 30 minutes corresponding to the east or west half of the 1:100,000 scale map sheets.

USGS 1-degree DEM

3 x 3 arc-second data spacing referenced horizontally on the geographic coordinate system (latitude / longitude) of the World Geodetic System of 1972 (WGS 72) or the World Geodetic System of 1984 (WGS 84). Elevations are in meters referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

GTOPO30

http://edcwww.cr.usgs.gov/products/elevation/gtopo30.html

Global 30 Arc-Second Elevation Dataset (GTOPO30) is a global raster Digital Elevation Model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). GTOPO30 was derived from a variety of raster and vector sources. The data is expressed in geographic coordinates (latitude/longitude) and is referenced to the World Geodetic System of 1984

(WGS84). The files are available in generic binary (16-bit signed integer) format and are distributed on CD-ROM, FTP (compressed), and 8-mm tape.

PART 3: ELEVATION DATA METADATA

Metadata is "data about data" and describes the content, quality, condition, and other characteristics of data. Part 3 contains examples of metadata that comply with the *Content Standard for Digital Geospatial Metadata* (FGDC-STD-001-1998). This part identifies those elements or entities that allow minimal compliancy to that standard. The purpose is twofold: 1) to allow for flexible implementation of metadata among a variety of producers and still comply to the standard, and 2) establish a base that will allow for the creation of a base profile that could be formalized through the FGDC process.

3.1 ELEVATION METADATA BY SECTIONS AND ELEMENTS

FGDC metadata is organized into 7 sections numbered sections 3.1.1 – 3.1.7 in this document. The section numbers in this document should not be confused with numbered sections of the FGDC standard. Each contains a series of elements that define the information content for metadata to document a set of digital geospatial data per the *Content Standards for Geospatial Metadata, Version 2.0.*

Those elements in highlights are considered mandatory elements because either 1) the FGDC standard states they are or 2) this guideline highly recommends they be included as part of the metadata. This means many elements considered by the FGDC to be Mandatory If Applicable and Optional may be mandatory elements to meet minimal compliancy for NDEP purposes. Explanatory information is included and, where needed, examples have been provided.

Included within each section of the metadata are extensions. They are extended elements to the Standard as defined by a dataset producer or user community, the FGDC/SWG Imagery Subgroup Remote Sensing Metadata Extensions Development Team in this case. The extensions included in this document are from a draft content standard developed by the remote sensing community. (*Content Standard for Digital Geospatial Metadata: Extensions for Remote Sensing Metadata (Final Draft*)). These extensions are provided when existing elements are not applicable or for when the existing standard falls short with respect to available elements. The official requirements and rules for the development of User Defined Extensions are documented in Appendix D of the FGDC *Content Standard for Digital Geospatial Metadata (FGDC-STD-001-1998).*

Some mandatory elements are specific to the dataset: that is, for a particular data product some elements may contain the same statement or information. This would allow a producer to develop "boilerplate" or generic metadata statements for some elements that are used for an entire data series. For instance, under Identification Information, the Purpose element for 7.5-minute USGS DEMs could contain this boilerplate statement:

> "DEMs can be used as source data in the production of digital orthophotos and as layers in geographic information systems for earth science analysis. DEMs can also serve as tools for volumetric analysis, for site location of towers, or for

drainage basin delineation. These data have been collected as part of the National Mapping Program."

This approach allows for the use of automated metadata creation applications for large numbers of datasets and reduces the need to perform customized metadata creation for every data file.

3.1.1 Identification Information

This section is 1 of 2 mandatory sections required by the FGDC standard. The other is the Metadata Reference Information section. This section is comprised of basic information about the dataset.

Identification_Information:
Citation:
Citation_Information:
Originator: *The creator of the dataset*
Publication_*Date*:
Title: *The name by which the dataset is known*.
Geospatial_Data_Presentation_Form: *The mode in which the data is represented (data model and format.)*

Description:
Abstract: *General information about the dataset. Describe the surface characteristics, for example: raw LIDAR mass points with up to 5 returns per point vs. DEM bare-earth processed to remove which features (buildings, vegetation, bridges, culverts, etc?); to what percent cleanliness; filtered to remove noise; shoreline profile enforced; etc.*
Purpose: *Why was this dataset created?*

Time_Period_of_Content
Time_Period_Information *"Use only one option for the time period information."*
Single_Date/Time
Calendar_Date: *This date is the collection date of the data. If your dataset spans different dates, use one of the choices below.*
OR
Multiple_Dates/Times
Calendar_Date:
OR
Range_of_Dates/Times:
Beginning_Date:
Ending_Date:

Status:
Progress:
Maintenance_and_Update_Frequency: *How often will the data be updated? For example, >unknown=, >weekly=, >monthly=, annually=, >irregular=, free text.*

Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: *Coordinates in decimal form degrees*
East_Bounding_Coordinate:
North_Bounding_Coordinate:
South_Bounding_Coordinate:

AND, if desired

Data Set G-Polygon:
G-Ring Point:
G-Ring Latitude:
G-Ring Longitude:

OR

G-Ring:

Keywords:
Theme:
Theme_Keyword_Thesaurus: *Unless you are using one, enter >none=*
Theme_Keyword: EX. Elevation data
Theme_Keyword: EX. LIDAR
Theme_Keyword: EX. first return *(repeatable, better to use as more keywords than a few)*
Place:
Place Keyword Thesaurus:
Place Keyword: *This should be mandatory.*

Access_Constraints: None *(there should not be any constraints on access if we live up to the intent of the NDEP)*

Use_Constraints: None. *(For example: here's the standard statement from USGS - Acknowledgement of the U.S. Geological Survey would be appreciated in products derived from these data.)*

Data_Set_Credit: *This is not a mandatory element but should be used if order to give credit to others for making the dataset possible. USGS does this on many of its cooperative datasets.*
Native_Data_Set_Environment: *This is not a mandatory element but is useful to describe the processing environment. It refers to the hardware and software used to process or create the dataset. It should be specific to the dataset. For instance, the processes for USGS DEM production have evolved over the 20+ years they been made and it is the process that largely determined the quality of the data. Therefore that information should be included in this element as it would appear to be highly relevant.*

3.1.2 Data Quality Information

Data_Quality_Information:
Attribute_Accuracy:
Attribute_Accuracy_Report:
Logical_Consistency_Report:
Completeness_Report:
Positional_Accuracy:
Horizontal Positional Accuracy:
Horizontal_Positional_Accuracy_ Report:
Horizontal Positional Accuracy (one of the following):

- *Compiled to meet __ (meters, feet) horizontal accuracy at 95 percent confidence level*
- *Tested __ (meters, feet) horizontal accuracy at 95% confidence level*

Quanitative_Horizontal_Positional_Accuracy_Assessment:
Horizontal _Positional_Accuracy_Value:
Horizontal _Positional_Accuracy_Explanation:

Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report:
Vertical Positional Accuracy (one or more of the following):

- *Compiled to meet __ (meters, feet) fundamental vertical accuracy at 95% confidence level in open terrain*
- *Compiled to meet __ (meters, feet) supplemental vertical accuracy at 95th percentile in (specify other) land cover categories*
- *Compiled to meet __ (meters, feet) consolidated vertical accuracy at 95th percentile in open terrain and all other land cover categories combined*
- *Tested __ (meters, feet) fundamental vertical accuracy at 95 percent confidence level in open terrain using* $RMSE_z$ *x 1.9600*
- *Tested __ (meters, feet) supplemental vertical accuracy at 95th percentile in (specify other) land cover categories*
- *Tested __ (meters, feet) consolidated vertical accuracy at 95th percentile in open terrain plus all other land cover categories combined*

Quanitative_Vertical_Positional_Accuracy_Assessment:
Vertical_Positional_Accuracy_Value:
Vertical_Positional_Accuracy_Explanation:
List checkpoint errors larger than 95th percentile when reporting tested values for supplemental vertical accuracy or consolidated vertical accuracy.

Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Publication_Date:
Title:
Geospatial_Data_Presentation_Form:

Publication_Information:
Publication_Place:
Publisher:
Type_of_Source_Media:
Source_Time_Period_of_Content:
Single_Date/Time
Calendar_Date: *This date is the collection date of the source data. If your source dataset spans different dates, use one of the choices below.*
OR
Multiple_Dates/Times
Calendar_Date:
OR
Range_of_Dates/Times:
Beginning_Date:
Ending_Date:
Source_Currentness_Reference:
Source_Citation_Abbreviation:
Source_Contribution:
Process_Step:
Process_Description:.
Source_Used_Citation_Abbreviation:
Process_Date:

3.1.3 Spatial Data Organization Information

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: *Raster*
Raster_Object_Information:
Raster_Object_Type: *Grid Cell*
Row_count:
Column_count:

3.1.4 Spatial Reference Information

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Geographic:
Latitude_Resolution +
Longitude Resolution+
Geographic_Coordinate_Units
OR
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name:
Universal_Transverse_Mercator:
UTM_Zone_Number:

Transverse_Mercator:
Scale_Factor_at_Central_Meridian:
Longitude_of_Central_Meridian:
Latitude_of_Projection_Origin:
False_Easting:
False_Northing:
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method:
Coordinate_Representation:
Abscissa_Resolution:
Ordinate_Resolution:
Planar_Distance_Units:
Geodetic_Model:
Horizontal_Datum_Name:
Ellipsoid_Name:
Semi-major_Axis:
Denominator_of_Flattening_Ratio:
Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
Altitude_Datum_Name:
Altitude_Resolution:
Altitude_Distance_Units:
Altitude_Encoding_Method:

OR/ AND, if applicable (if the model is bathymetric data or contains bathymetric data)

Vertical_Coordinate_System_Definition:
Depth System_Definition:
Depth_Datum_Name:
Depth_Resolution:
Depth_Distance_Units:
Depth_Encoding_Method:

3.1.5 Entity and Attribute Information

Entity_and_Attribute_Information:
Overview_Description:
Entity_and_Attribute_Overview:
Entity_and_Attribute_Detail_Citation:

3.1.6 Distribution Information

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:

Contact_Organization:
Contact_Address:
Address_Type:
Address:
City:
State_or_Province:
Postal_Code:
Contact_Voice_Telephone:
Hours_of_Service:
Contact_Instructions:
Resource_Description:
Distribution_Liability:
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name:
Format_Information_Content:
Transfer_Size:
Digital_Transfer_Option:
Offline_Option:
Offline_Media:
Recording_Capacity:
Recording_Density:
Recording_Density_Units:
Recording_Format:
Online_Option:
Computer Contact Information:
Network Address
Network Resource Name:
Fees:
Ordering_Instructions:

3.1.7 Metadata Reference Information

Metadata_Reference_Information:
Metadata_Date:
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization:
Contact_Address:
Address_Type:
State_or_Province:
Postal_Code:
Contact_Voice_Telephone:
Contact_Facsimile_Telephone:

Metadata_Standard_Name:
Metadata_Standard_Version:
Metadata Extensions:

3.2 EXAMPLES OF METADATA BY ELEVATION MODEL TYPES

The following are examples of metadata by elevation model type: (1) Mass points, (2) Break lines, (3) TINs, (4) Grids, (5) Contours, and (6) Cross Sections. While each is FGDC compliant, they are presented only as examples only. The NDEP strongly recommends that member organizations provide information about their data that goes beyond the minimal mandatory implementation (Identification and Metadata Reference Information only) and adhere to that Standard's content format as closely as they can to facilitate use of the data to as large an audience as possible.

3.2.1 Mass Points

This template is an example of the metadata requirements for mass points from high resolution LIDAR. It is meant as a guide only. Where bolded text appears, user input is required. The other elements are headings and do not require input.

Section 1 – Identification Information.
It is always mandatory.

Identification_Information:
Citation:
Citation_Information:
Originator: Dataset creator, e.g. North Carolina Department of Natural Resources
Publication_Date: N/A
Title: The name by which the dataset is known.
Geospatial_Data_Presentation_Form: The mode in which the data is represented. (Data model and format.) Because the raw data formats will be fairly unique we'll need to either include a description of the format within the GDA metadata or reference a snapshot of the format preserved at some location. E.g. mass points

Description:
Abstract: General information about the dataset. Describe the surface characteristics. , For example: raw LIDAR mass points with up to 5 returns per point to what percent cleanliness; filtered to remove noise; shoreline profile enforced; etc.
Purpose: Why was this dataset created?

Time_Period_of_Content
Time_Period_Information
Single_Date/Time

Calendar_Date: This date is the collection date of the data. If your dataset spans different dates, use one of the choices below.
OR
Multiple_Dates/Times
Calendar_Date:
OR
Range_of_Dates/Times:
Beginning_Date:
Ending_Date:

Status:
Progress:
Maintenance_and_Update_Frequency: How often will the data be updated? For example, >unknown=, >weekly=, >monthly=, annually=, >irregular=, free text.

Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: (Include coordinates in decimal form)
East_Bounding_Coordinate:
North_Bounding_Coordinate:
South_Bounding_Coordinate:
OR
Polygon Description: A series of x,y points in sufficient quantity to completely describe the polygon boundary.

Keywords:
Theme:
Theme_Keyword_Thesaurus: Unless you are using one, enter >none=
Theme_Keyword: Light Detection and Ranging.
Theme_Keyword: LIDAR

Access_Constraints: None (in theory, there shouldn't be any access constraints to NDEP elevation data)

Use_Constraints: None. Acknowledgement of the U.S. Geological Survey would be appreciated in products derived from these data.

Section 2 - Data Quality Information

Only the mandatory elements from this section are included. It would be worthwhile to include the *__mandatory if applicable__* *elements as well (Attribute Accuracy and Positional Accuracy). These are elements that users would be interested in.*

Data_Quality_Information:

Logical_Consistency_Report: Describe any fidelity of relationships encoded in the data structure of the LIDAR data.
Completeness_Report: Document the inclusion of features for your dataset.
Positional Accuracy:
Horizontal Positional Accuracy:
Horizontal Positional Accuracy Report:
Quantitative Horizontal Positional Accuracy Assessment:
Horizontal Positional Accuracy Value
Horizontal Positional Accuracy Explanation:
Positional Accuracy:
Vertical Positional Accuracy:
Vertical Positional Accuracy Report:
Quantitative Vertical Positional Accuracy Assessment:
Vertical Positional Accuracy Value
Vertical Positional Accuracy Explanation:
Lineage: USED ONLY FOR PRODUCTS DERIVED FROM RAW LIDAR DATA
(For the lineage, you need to include any sources that have contributed to your dataset. Repeat Source_Citation, Citation_Information for each source used. Also, you may repeat Source_Time_Period_of_Content, Time_Period_Information as many times as needed.)
Source_Information: (All source information is mandatory if applicable.)
Source_Citation:
Citation_Information:
Originator:
Publication_Date:
Title:
Geospatial_Data_Presentation_Form:
Publication_Information:
Publication_Place:
Publisher:
Type_of_Source_Media:
Source_Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date:
Ending_Date:
Source_Currentness_Reference:
Source_Citation_Abbreviation:
Source_Contribution:

Process_Step:
Production Narrative: How was this dataset created? Items to include:
- LIDAR Acquisition Procedures:
- Scanner, GPS, IMU used
- Maximum GPS PDOP allowed during data collection session(s)
- Maximum allowable distance from GPS ground stations during data collection

- Data acquisition flight height
- Swath width (in degrees, from nadir)
- Distance between flight lines
- Methods and procedures used for scanner calibration
- Number of returns collected per scanner pulse
- Nominal Post Spacing
- Description of any/all post-collection processing
- Accuracy testing procedure and results

Section 3 – Spatial Data Organization Information

You would probably want to use >Direct_Spatial_Reference_Method=. Since there are several choices with this method, it is recommended that you refer to the workbook.

Spatial_Data_Organization_Information

Indirect_Spatial_Reference: Name of types of geographic features, addressing schemes, or other means through which locations are referenced in the dataset.
OR
Direct_Spatial_Reference_Method:
(Includes choices under this method) It would be best to use the workbook to work through this section.

Section 4 – Spatial Reference Information

Spatial_Reference_Information:

Example:
Horizontal_Coordinate_System_Definition:
    Planar:
        Grid_Coordinate_System:
            Grid_Coordinate_System_Name:
            Universal_Transverse_Mercator:
                UTM_Zone_Number:
                Transverse_Mercator:
                    Scale_Factor_at_Central_Meridian:
                    Longitude_of_Central_Meridian:
                    Latitude_of_Projection_Origin:
                    False_Easting:
                    False_Northing:
        Planar_Coordinate_Information:
            Planar_Coordinate_Encoding_Method:
            Coordinate_Representation:
                Abscissa_Resolution:
                Ordinate_Resolution:
            Planar_Distance_Units:
    Geodetic_Model:
        Horizontal_Datum_Name:

Ellipsoid_Name:
Semi-major_Axis:
Denominator_of_Flattening_Ratio:

Section 5 – Entity and Attribute Information

There may be datasets for which you may want to give a more detailed description of the attributes used to describe your data, and if so, use the workbook to make your choices. The overview is probably sufficient in most cases to give the user enough information.

Entity_and_Attribute_Information:
Overview_Description:
Entity_and_Attribute_Overview: Detailed summary of the information contained in the dataset.
Entity_and_Attribute_Detail_Citation: Reference to the complete description of the entity types, attributes, and attribute values for the dataset. For example, we would cite the NMP standard that describes the attributes.

Section 6 - Distribution Information

This section would only be used if the dataset were going to be distributed. (For instance, raw LIDAR may not be a distributed dataset.) The elements contained below are the only mandatory elements in this section.

Distribution_Information:
Distributor:
Resource Description
Contact_Information:
Contact_Organization_Primary:
Contact_Organization:
Contact_Address:
Address_Type:
Address:
City:
State_or_Province:
Postal_Code:
Contact_Voice_Telephone:
Distribution_Liability:

Section 7 – Metadata Reference Information
A Mandatory section.

Metadata_Reference_Information:
Metadata_Date: When was this metadata created?
Metadata_Standard_Name: Will usually be >Content Standard for Digital Geospatial Metadata=
Metadata_Standard_Version: FGDC-STD-001-1998

3.2.2 Elevation Metadata Example - Breaklines

```
IDENTIFICATION_INFORMATION

  Citation:
    Citation_Information:
      Originator: ABC Surveying & Mapping
      Publication_Date: 20020815
      Title: Sample Metadata
      Edition: 1.0
      Geospatial_Data_Presentation_Form: Map
      Publication_Information:
        Publication_Place: Insert City and/or State
        Publisher: ABC Surveying & Mapping
      Other_Citation_Details:
      Online_Linkage: \\Insert_path\DTM_brk_lines.shp
      Larger_Work_Citation:
        Citation_Information:
          Originator:
          Publication_Date:
          Title:
          Publication_Information:
            Publication_Place:
            Publisher: Flood County
          Online_Linkage:
  Description:
    Abstract:
Breaklines in a Digital Terrain Model (DTM) are linear
features that describe a change in the smoothness or
continuity of a surface. Breaklines define the break in
elevation between two surfaces with different slopes and
are associated with linear features such as stream
centerlines, shorelines, drainage ditches, tops and bottoms
of stream banks, ridge lines, levees, bulkheads, seawalls,
retaining walls, selected manmade features that constrict
or control the flow of water, etc. Breaklines can either be
2 dimensional (with x/y coordinates only) or 3 dimensional
(with x/y/z coordinates), depending on the type of surface
being generated.
    Purpose:
      To create a hydro-enforced elevation model for
hydrologic and hydraulic      purposes to ensure the
downward flow of water.
    Supplemental_Information:
This dataset of Flood County originated as 2D breaklines
created from orthophotos from aerial imagery flown in March
2001, and subsequently converted into 3D breaklines from
GPS and conventional field surveys performed in April 2001.
```

```
  Time_Period_of_Content:
    Time_Period_Information:
      Range_of_Dates/Times:
        Beginning_Date: March 2001
        Ending_Date: April 2001
    Currentness_Reference:
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: As needed
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -75.000000
      East_Bounding_Coordinate: -74.500000
      North_Bounding_Coordinate: 35.000000
      South_Bounding_Coordinate: 34.500000
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus: None
      Theme_Keyword: Contour
      Theme_Keyword: DEM
      Theme_Keyword: DSM
      Theme_Keyword: DTM
      Theme_Keyword: Elevation
      Theme_Keyword: Height
      Theme_Keyword: Orthophoto
      Theme_Keyword: Photogrammetry
      Theme_Keyword: Planimetric
      Theme_Keyword: Stereo Photogrammetry
      Theme_Keyword: TIN
      Theme_Keyword: ESRI
      Theme_Keyword: Shapefile
      Theme_Keyword: Contour

    Place:
      Place_Keyword_Thesaurus: None
      Place_Keyword: Insert City or Town
      Place_Keyword: Flood County
      Place_Keyword: Insert State
      Place_Keyword: United States
  Access_Constraints:
    Requests serviced by email or ftp
  Use_Constraints:
Neither Flood County nor its employees makes any warranty,
express or implied, or assumes any legal liability or
responsibility for the accuracy, completeness or usefulness
of the defined data source.
  Point_of_Contact:
```

```
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: ABC Surveying & Mapping
        Contact_Person: John Doe
      Contact_Position: Surveying and Mapping Manager
      Contact_Address:
        Address_Type: mailing and physical address
        Address: Insert Address
        City: Insert City
        State_or_Province: Insert State
        Postal_Code: Insert Zip
        Country: United States
      Contact_Voice_Telephone: 800 555-1234
      Contact_Facsimile_Telephone: 800 555-6789
      Contact_Electronic_Mail_Address:
survey_manager@abcmapping.com
      Hours_of_Service: 9:00 a.m. - 5:00 p.m.
  Data_Set_Credit:
     This data set was created to support Flood County
Mapping Program

  Native_Data_Set_Environment:
    ArcView version 3.2 shapefile format
    c:\breaklines\breaklines.shp
    AutoCAD 2000
    C:\breaklines\breaklines\dxf
```

DATA_QUALITY_INFORMATION

```
  Attribute_Accuracy:
    Attribute_Accuracy_Report:
Explanation of the accuracy of the identification of the
entities and assignments of values in the data set and a
description of the tests used;
e.g. Attributes for selected stream shore lines, and tops
and bottoms of stream banks, stream centerlines and 2D
coordinate line strings for these breaklines were created
from on-screen digitizing of ortho-photography.  Attributes
were verified in the field, and z-values (elevations) of
selected points (water surface elevations and elevations of
cross section break points at tops and bottoms of stream
banks) were added from GPS and conventional surveys.
Database information is verified through routines that
verify values and definitions for attributes. Line work is
verified for consistency. All terrestrial measurements are
```

```
confirmed by survey team leaders using least squares
adjustments and/or survey adjustment software.
  Logical_Consistency_Report:
    Explanation of the fidelity relationships in the data
sets
    and the tests used.
    e.g. Format - Arc Node topology exists (clean and
build)
    CAD - Level structure exists (layers by feature type)
  Completeness_Report:
Information about omissions, selection criteria,
generalizations, definitions used, and rules to derive data
sets. Data is complete for hydrologic and hydraulic
analysis for drainage areas greater than 640 acres. Data is
sufficient for Flood County needs but will vary based on
other user requirements. Flow and connectivity for
hydraulics have been tested.
  Positional_Accuracy:
    Horizontal_Positional_Accuracy:
      Horizontal_Positional_Accuracy_Report:
Explanation of the accuracy of the horizontal coordinate
measurements
and a description of the tests used. One or more of the
following horizontal accuracy requirement industry
standards was followed:
        1. American Society for Photogrammetry and Remote
Sensing
        (ASPRS) Accuracy Standards for Large Scale Maps,
1990.
        2. United States National Map Accuracy Standards,
Office of
        Management and Budget (OMB), 1947.
        3. National Standard for Spatial Data Accuracy
(NSSDA), 1998.
The dataset from ortho-photography was created from 1:4800
scale mapping. The horizontal accuracy is within National
Map Accuracy Standards, with horizontal accuracy of 15.2
feet at the 95% confidence level. Datasets from field
surveys were created by GPS and terrestrial methods not
exceeding second order standards of 20 PPM or less.
    Vertical_Positional_Accuracy:
      Vertical_Positional_Accuracy_Report:
Explanation of the accuracy of the vertical coordinate
measurements and a description of the tests used. The
following industry standard was followed: National Oceanic
and Atmospheric Administration Technical Manual NOS NGS-58,
"Guidelines for Establishing GPS-Derived Ellipsoid Heights
```

```
(Standards: 2 cm and 5 cm)." Three dimensional breakline
dataset from field surveys were created by GPS and
terrestrial methods utilizing NOS NGS-58 guidelines for 5cm
local network accuracy at the 95 percent confidence level.
  Lineage:
    Source_Information:
      Source_Citation:
        Citation_Information:
          Originator: ABC Surveying & Mapping
          Publication_Date: 20020615
          Title: Sample Metadata
          Edition: 1.0
          Geospatial_Data_Presentation_Form: map
          Publication_Information:
            Publication_Place: Insert City and/or State
            Publisher: ABC Surveying & Mapping
          Other_Citation_Details:
            Air Photography and aero-triangulation was
flown and
            processed by (insert citation info here)
          Online_Linkage: \\Insert_path\DTM_brk_lines.shp
          Larger_Work_Citation:
            Citation_Information:
              Originator:
              Publication_Date:
              Title:
              Publication_Information:
                Publication_Place:
                Publisher: Flood County
              Online_Linkage:
      Source_Scale_Denominator: 4800
      Type_of_Source_Media: Digital orthophotos
      Source_Time_Period_of_Content:
        Time_Period_Information:
          Range_of_Dates/Times:
            Beginning_Date: 20000315
            Ending_Date: 20000401
        Source_Currentness_Reference: Current at the time
of flight
      Source_Citation_Abbreviation:
      Source_Contribution:
    Process_Step 1:
      Process_Description:
2D breaklines were derived through on screen digitizing of
the orthophotography as provided by Flood County. The line
work was captured as two dimensional lines with x/y
coordinates only. Principal breaklines that support
```

```
hydrologic and hydraulic models were captured which include
stream shorelines, centerline and approximate delineation
of bottom and top of stream banks, as well as hydraulic
structures (dams, bridges and culverts) that constrict or
impede the flow of water. Whereas the orthophotos clearly
delineate shorelines, the tops and bottoms of stream banks
can only be estimated from such imagery.
      Source_Used_Citation_Abbreviation:
      Process_Date: 20020715
      Source_Produced_Citation_Abbreviation:
      Process_Contact:
        Contact_Information:
          Contact_Person_Primary:
            Contact_Organization: ABC Surveying & Mapping
            Contact_Person: John Doe
          Contact_Position: Surveying and Mapping Manager
          Contact_Address:
            Address_Type: mailing and physical address
            Address: Insert Address
            City: Insert City
            State_or_Province: Insert State
            Postal_Code: Insert Zip
            Country: United States
          Contact_Voice_Telephone: 800 555-1234
          Contact_Facsimile_Telephone: 800 555-6789
          Contact_Electronic_Mail_Address:
survey_manager@abcmapping.com
          Hours_of_Service: 9:00 a.m. - 5:00 p.m.
    Process_Step 2:
      Process_Description:
GPS control for surveying cross sections and breaklines was
established with RTK GPS, utilizing NGS 58 guidelines for
local network accuracy of 5 cm at the 95% confidence level.
Intervisible pairs of stations were established to use for
conventional surveying of selected cross sections and break
points used to convert 2D breaklines into 3D breaklines.
Conventional measurements were surveyed between the
intervisible pairs to verify that the stations were within
5 cm of each other. Any discrepancies larger than 5 cm
would have required the GPS surveys of inconsistent points
to be repeated.
      Source_Used_Citation_Abbreviation:
      Process_Date: 20010722
      Source_Produced_Citation_Abbreviation:
      Process_Contact:
        Contact_Information:
          Contact_Person_Primary:
```

```
            Contact_Organization: ABC Surveying & Mapping
            Contact_Person: John Doe
          Contact_Position: Surveying and Mapping Manager
          Contact_Address:
            Address_Type: mailing and physical address
            Address: Insert Address
            City: Insert City
            State_or_Province: Insert State
            Postal_Code: Insert Zip
            Country: United States
          Contact_Voice_Telephone: 800 555-1234
          Contact_Facsimile_Telephone: 800 555-6789
          Contact_Electronic_Mail_Address:
survey_manager@abcmapping.com
          Hours_of_Service: 9:00 a.m. - 5:00 p.m.
    Process_Step 3:
      Process_Description:
In accordance with section A.4.6, Appendix A, Guidance for
Aerial Mapping and Surveying, of FEMA's "Guidelines and
Specifications for Flood Hazard Mapping
Partners"(www.fema.gov/mit/tsd/dl_cgs.htm), cross sections
were surveyed immediately downstream from all major bridges
and culverts, and at selected locations where there were
distinct changes in the shape of stream banks or stream
channel geometry, e.g., waterfalls. Gradient break points
at tops and bottoms of stream banks, and water surface
elevations, were used to add z-values (elevations) to the
2D breaklines from Process Step 1, to hydro-enforce the
shorelines to ensure the downward flow of water, and to
adjust the horizontal alignment of the breaklines so that
they are correct at the cross sections to be used for
hydraulic modeling. Conventional survey procedures were
used, with each cross section tied to the intervisible
pairs of GPS control points, from Process Step 2, for each
cross section. Openings in bridges and culverts were also
surveyed to establish additional 3D breaklines that model
constrictions in water flow beneath bridges and through
culverts.
      Source_Used_Citation_Abbreviation:
      Process_Date: 20010715
      Source_Produced_Citation_Abbreviation:
      Process_Contact:
        Contact_Information:
          Contact_Person_Primary:
            Contact_Organization: ABC Surveying & Mapping
            Contact_Person: John Doe
          Contact_Position: Surveying and Mapping Manager
```

```
          Contact_Address:
            Address_Type: mailing and physical address
            Address: Insert Address
            City: Insert City
            State_or_Province: Insert State
            Postal_Code: Insert Zip
            Country: United States
          Contact_Voice_Telephone: 800 555-1234
          Contact_Facsimile_Telephone: 800 555-6789
          Contact_Electronic_Mail_Address:
survey_manager@abcmapping.com
          Hours_of_Service: 9:00 a.m. - 5:00 p.m.
```

SPATIAL_DATA_ORGANIZATION_INFORMATION

```
  Direct_Spatial_Reference_Method: Vector
  Point_and_Vector_Object_Information:
    SDTS_Terms_Description:
      SDTS_Point_and_Vector_Object_Type:
      Point_and_Vector_Object_Count: 850
```

SPATIAL_REFERENCE_INFORMATION

```
  Horizontal_Coordinate_System_Definition:
    Planar:
      Map_Projection:
        Map_Projection_Name: Geographic
      Planar_Coordinate_Information:
        Planar_Coordinate_Encoding_Method: Coordinate pair
        Coordinate_Representation:

          Abscissa_Resolution: 0.01 ft
          Ordinate_Resolution: 0.01 ft
        Planar_Distance_Units: Feet
    Geodetic_Model:
      Horizontal_Datum_Name: North American Datum of 1983
      Ellipsoid_Name: Geodetic Reference System 80
      Semi-major_Axis: 6,378,137
      Denominator_of_Flattening_Ratio: 298.257
  Vertical_Coordinate_System_Definition:
    Altitude_System_Definition:
      Altitude_Datum_Name: North American Vertical Datum of
1988 utilizing
      Geoid99
      Altitude_Resolution: 0.01 ft
      Altitude_Distance_Units: Feet
```

```
      Altitude_Encoding_Method: Explicit elevation included
with horizontal
      cordinates
```

ENTITY_AND_ATTRIBUTE_INFORMATION

```
  Detailed_Description:Enter each attribute and definition
e.g.
    Entity_Type:
      Entity_Type_Label: breaklines.dbf
      Entity_Type_Definition: Shapefile Attribute Table
      Entity_Type_Definition_Source: None
    Attribute:
      Attribute_Label: Entity
      Attribute_Definition: Internal feature
      Attribute_Definition_Source: ESRI
      Attribute_Domain_Values:
        Unrepresentable_Domain: Program generated numbers
    Attribute:
      Attribute_Label: Layer
      Attribute_Definition:
      Attribute_Definition_Source:
      Attribute_Domain_Values:
        Unrepresentable_Domain: Character Field
    Attribute:
      Attribute_Label: Level
      Attribute_Definition:
      Attribute_Definition_Source:
      Attribute_Domain_Values:
        Unrepresentable_Domain: Character Field
    Attribute:
      Attribute_Label: Elevation
      Attribute_Definition: Elevation to the nearest
1/100th ft above msl
      Attribute_Definition_Source:
      Attribute_Domain_Values:
        Enumerated_Domain:
          Enumerated_Domain_Value: 0.00000
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
          Enumerated_Domain_Value: 563.40000
          Enumerated_Domain_Value_Definition:
          Enumerated_Domain_Value_Definition_Source:
    Attribute:
      Attribute_Label: Color
      Attribute_Definition:
      Attribute_Definition_Source:
```

```
      Attribute_Domain_Values:
        Unrepresentable_Domain: Layer set
        Range_Domain: Vertical range -0.50 to 101.67 ft
  Overview_Description:
    Entity_and_Attribute_Overview:
    Entity_and_Attribute_Detail_Citation:
Tim, add section 5.1.2.4.2 (range) here
```

DISTRIBUTION_INFORMATION

```
  Distributor:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: ABC Surveying & Mapping
        Contact_Person: John Doe
      Contact_Position: Surveying and Mapping Manager
      Contact_Address:
        Address_Type: mailing and physical address
        Address: Insert Address
        City: Insert City
        State_or_Province: Insert State
        Postal_Code: Insert Zip
        Country: United States
      Contact_Voice_Telephone: 800 555-1234
      Contact_Facsimile_Telephone: 800 555-6789
      Contact_Electronic_Mail_Address:
survey_manager@abcmapping.com
      Hours_of_Service: 9:00 a.m. - 5:00 p.m.
  Resource_Description:
    Digital file format only.
  Distribution_Liability:
The 3D breaklines are only known to have the specified
accuracy at locations where surveyed cross sections were
used to modify the 2D breaklines from orthophotos.
Elsewhere, the final breakline elevations were interpolated
between the surveyed cross sections. Neither ABC Surveying
& Mapping nor its employees makes any warranty, express or
implied, or assumes any legal liability or responsibility
for the accuracy, completeness or usefulness of the defined
data source at points other than where ground surveys were
performed.
  Standard_Order_Process:
    Digital_Form:
      Digital_Transfer_Information:
        Format_Name:breallines
      Digital_Transfer_Option:
        Offline_Option:
```

```
          Offline_Media: CD
          Recording_Format: CD
          Compatibility_Information:
    Fees: Cost of producing or sending files
    Ordering_Instructions:
      enter Ordering Instructions
```

METADATA_REFERENCE_INFORMATION

```
  Metadata_Date: 20010901
  Metadata_Review_Date:
  Metadata_Contact:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: ABC Surveying & Mapping
        Contact_Person: John Doe
      Contact_Position: Surveying and Mapping Manager
      Contact_Address:
        Address_Type: Mailing and physical address
        Address: Insert Address
        City: Insert City
        State_or_Province: Insert State
        Postal_Code: Insert Zip
        Country: United States
      Contact_Voice_Telephone: 800 555-1234
      Contact_Facsimile_Telephone: 800 555-6789
      Contact_Electronic_Mail_Address:
survey_manager@abcmapping.com
      Hours_of_Service: 9:00 a.m. - 5:00 p.m.
  Metadata_Standard_Name: FGDC CSDGM
  Metadata_Standard_Version: FGDC-STD-001-1998
```

3.2.3 Elevation Metadata Example - Grids

The following is an example of a minimal DEM metadata template for USGS 7.5-minute DEM, 7.5-minute Alaska DEM, and 15-minute Alaska DEM products. The information contained in this example is for the mandatory Identification Information and Metadata Reference Information sections and the Data Quality Information Section that is Mandatory If Applicable.

Comments in red were generated by XMLInput (ftp://ftpmcmc.er.usgs.gov/release/xmlinput), a USGS-created Java application for creating, modifying, and saving XML-based metadata templates. For the most part, text in red includes comments that address file specific element requirements. Note that most elements domains (in black) are boilerplate or generic statements that are product specific.

Identification_Information:
Citation:
Citation_Information:
Product_Name: 7.5-minute DEM (per NMP Technical Standards)
Title: Filename of DEM
Geospatial_Data_Presentation_Form: model

Keywords:
Theme:
Theme_Keyword: DEM
Theme_Keyword: digital elevation model
Theme_Keyword: digital terrain model
Theme_Keyword: LIDAR DEM (retain if applicable, otherwise delete)
Theme_Keyword: IFSAR DEM (retain if applicable, otherwise delete)
Theme_Keyword: hypsography
Theme_Keyword: altitude
Theme_Keyword: height

Data_Set_Credit: Retain data credit element for data produced by cooperator. Delete for contractor data.

Native_Data_Set_Environment: Name of software(s) and version, workstation operating system (OS) and version. For example: LT4X software, version 1997; Delta3D software, version 1993; Sunblade 100 workstation, Solaris 8 OS, software release 10/00.

Data_Quality_Information:
Logical Consistency Report:
Completeness Report:
Positional_Accuracy:
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report: (retain if applicable, otherwise rewrite as needed to report on your method of testing) The vertical RMSE value is used to describe the vertical accuracy of a DEM and encompasses random and systematic errors remaining after DEM production and editing. The RMSE may be computed by one of two basic methods. One method of RMSE calculation requires that the DEM be tested against independent checkpoints of higher order accuracy than that expected for the DEM itself. These checkpoints may be derived from an independent aerotriangulation (AT) solution or from independent ground surveys. The RMSE calculated from these points is considered an "absolute" measure of error with respect to the ground. When the RMSE is computed using checkpoint elevations from AT or ground surveys, the resulting value is encoded in data element 2 of record C.

Another method of RMSE calculation uses checkpoint elevations from the immediate DEM source (such as map contours or map control). The resulting value is considered a "relative" accuracy value (measured relative to its source) and is encoded in data element 5 of record C. Checkpoints are well distributed with values that represent the surrounding terrain. Acceptable checkpoints include, in order of preference, field control, AT checkpoints, spot elevations, or points on contours from existing source maps. A minimum of 28 checkpoints per DEM is required to compute the RMSE, which is composed of a single test using 20 interior points and 8 edge points. Edge points are those located along, at, or near the quadrangle neatlines and are deemed by the editor to be useful for evaluating the accuracy of the edge of the DEM. Quality control personnel within the USGS collect checkpoint data and compare the DEM with the quadrangle hypsography.

There are three types of DEM errors: blunders, systematic, and random. These errors are reduced in magnitude by editing but cannot be completely eliminated. Blunders are errors of major proportions and are easily identified and corrected during interactive editing. Systematic errors follow some fixed pattern and are introduced by data collection procedures and systems. The DEMs may have been processed, edited, and/or smoothed for consistency to remove identifiable systematic errors. These error artifacts include vertical elevation shifts, misinterpretation of terrain surface because of trees, buildings, and shadows, and fictitious ridges, tops, benches, or striations. Random errors result from unknown or accidental causes and are not readily identified or corrected.

For DEMs derived from contours, a vertical RMSE of one-half of the contour interval, determined from the source map, is the maximum permitted. Systematic errors may not exceed one contour interval on the source graphic.

Quantitative_Vertical_Positional_Accuracy_Assessment:
"vertacce" is non repeatable, retain applicable method of following two elements and delete other. If another test method has been used, please enter method.

Vertical_Positional_Accuracy_Explanation:
(retain if applicable, otherwise delete) RMSE calculated from relative checkpoints (map contours or map control).

Vertical_Positional_Accuracy_Explanation:
(retain if applicable, otherwise delete) RMSE calculated from independent checkpoints (AT or ground control).

Lineage:
Source_Information:
Source_Citation: (Data base DLG hypsography)

Citation_Information:
Originator: U.S. Geological Survey
Publication_Date:
YYYYMM, or YYYY date when source DLG was created or otherwise made available.
Title: Filename of data base DLG, For example, DUTCH JOHN, UT-WY
Geospatial_Data_Presentation_Form: vector digital data
Publication_Information:
Publication_Place: Reston, VA
Publisher: U.S. Geological Survey
Source_Scale_Denominator: 24000
Type_of_Source_Media: online
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: YYYYMM, YYYY, or Unknown
Source_Citation_Abbreviation: HYPSO
Source_Contribution: Digital line graph hypsographic information interpolated to form a rectangular array of elevation posts within bounding limit of 7.5-minute DEM.

Source_Information:
Source_Citation: (Data base DLG hydrography)
Citation_Information:
Originator: U.S. Geological Survey
Publication_Date:
YYYYMM, or YYYY date when source DLG was created or otherwise made available.
Title: Filename of data base DLG, For example, DUTCH JOHN, UT-WY
Geospatial_Data_Presentation_Form: vector digital data
Publication_Information:
Publication_Place: Reston, VA
Publisher: U.S. Geological Survey
Source_Scale_Denominator: 24000
Type_of_Source_Media: online
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: YYYYMM, YYYY, or Unknown
Source_Citation_Abbreviation: HYDRO2
Source_Contribution: Digital line graph water body information for inclusion for inclusion with hypsography as supplemental contours and breaklines prior to gridding DEM.

Source_Information:
Source_Citation: (Tagged Vector Contours (TVC) from map contours)
Citation_Information:

Originator: U.S. Geological Survey
Originator:
Optional Entry - name of primary contractor or cooperator that created source. If provided by contractor, information will be used for internal purposes only, not for release to public, not to be uploaded into data base.
Originator:
Optional Entry - name of sub contractor that created source. Information will be used for internal purposes only, not for release to public, not to be uploaded into database.
Publication_Date: YYYYMM date when TVC was created.
Title: Filename of TVC
Geospatial_Data_Presentation_Form: vector digital data
Publication_Information:
Publication_Place:
City and state where intermediate data is stored. For example: TVCs are currently stored at Denver, CO; Menlo Park, CA; Reston, VA; and Rolla, MO.
Publisher: U.S. Geological Survey
Source_Scale_Denominator: 20000, 24000, 25000, or 63360
Type_of_Source_Media:
stable-based material, disc (ftp server), or CD-ROM.
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: YYYYMM or YYYY
Source_Citation_Abbreviation: CONTOURS2
Source_Contribution: Vector hypsographic information with water bodies merged as supplemental contours and breaklines prior to gridding DEM.

Source_Information:
Source_Citation: (for water body edit of DEM produced)
Citation_Information:
Originator: U.S. Geological Survey
Publication_Date: YYYYMM water body edit date
Title: Map name
Geospatial_Data_Presentation_Form: vector digital data
Publication_Information:
Publication_Place: Reston, VA
Publisher: U.S. Geological Survey
Source_Scale_Denominator: 20000, 24000, 25000, or 63360
Type_of_Source_Media: stable-based material
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date:

YYYYMM, or YYYY date of hydrography if known, or the latest date of the maps source imagery.
Source_Citation_Abbreviation: WATER BODY
Source_Contribution: Vector water body information draped on DEM and leveled as part of the raster edit.

Source_Information:
Source_Citation: (for DEM produced)
Citation_Information:
Originator: U.S. Geological Survey
Publication_Date: YYYYMM date when DEM was completed
Title: Filename of DEM
Geospatial_Data_Presentation_Form: model
Publication_Information:
Publication_Place: Reston, VA
Publisher: U.S. Geological Survey
Source_Scale_Denominator: 24000
Type_of_Source_Media: Disc (ftp server), or CD-ROM
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: YYYYMM
Source_Citation_Abbreviation: DEM
Source_Contribution: Rectangular array of elevation posts within bounding limit of 7.5-minute DEM.

Source_Information:
Source_Citation:
"NAPP" example for use with DEMs generated from aerial photography. Retain if applicable to DEM process codes 1, or 2; otherwise delete element.
Citation_Information:
Originator: U.S. Geological Survey
Publication_Date:
YYYYMMDD, YYYYMM, or YYYY date when photography was made available to the public.
Title:
NAPP filmstrip reference or other reference title for supplemental photography
Geospatial_Data_Presentation_Form: remote-sensing image
Publication_Information:
Publication_Place: Reston, VA
Publisher: U.S. Geological Survey
Source_Scale_Denominator: 20000, 40000, or other scale
Type_of_Source_Media: filmstrip
Source_Time_Period_of_Content:
Time_Period_Information:

Range_of_Dates/Times:
Beginning_Date: earliest YYYYMMDD date of photography
Ending_Date: latest YYYYMMDD date of photography
Source_Citation_Abbreviation:
NAPP or PHOTO (use PHOTO for supplemental photography)
Source_Contribution: Elevation values derived from stereo photography.

Source_Information:
Source_Citation:
"Ground Control" example for use with DEMs generated from LIDAR, IFSAR, or aerial photography. Retain if applicable to DEM process codes 1, 2, or 7; otherwise delete element.
Citation_Information:
Originator: National Geodetic Survey
Publication_Date:
YYYYMMDD, or YYYYMM date when data was released to public.
Title:
CD-ROM name or other reference name dataset is known by.
Geospatial_Data_Presentation_Form: digital data
Publication_Information:
Publication_Place: Silver Spring, MD
Publisher: National Geodetic Survey
Type_of_Source_Media: CD-ROM
Source_Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: earliest YYYYMMDD date of horizontal control
Ending_Date: latest YYYYMMDD date of horizontal control
Source_Citation_Abbreviation: CONTROL
Source_Contribution: Ground control points.

Process_Step:
Process_Description: DLG/hypsography - the DEM is produced from DLG hypso/hydro data collected from large-scale (1:24,000-scale) USGS topographic maps. Contours, lakes, ponds, reservoirs, and single- and double-line streams/rivers are collected as part of a single vector file during the compilation stage. The commercial software LT4X is used either to edit existing DLG hypso/hydro overlays or to compile the DLGs from raster scan files. The elevation information is extracted from the DLG with a gridding algorithm, and the data are assembled into the USGS-formatted DEM. The gridding process utilizes a weighted algorithm to derive a single grid value from data gathered in 4, 8, or 16 linear directions to the nearest contour before repeating the cycle for the next grid value. Normally the eight-direction algorithm is used when gridding.
Source_Used_Citation_Abbreviation: HYPSO
Source_Used_Citation_Abbreviation: HYDRO

Process_Date: Unknown
Process_Contact: All contact information is optional: if provided by contractor information will be used for internal purposes only, not for release to public, not to be uploaded into data base.
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Name of contractor or cooperator
Contact_Person: Technical person that oversees process
Contact_Address:
Address_Type: mailing and physical address
Address:
City:
State_or_Province:
Postal_Code:
Contact_Voice_Telephone:
Contact_Electronic_Mail_Address:

Process_Step:
Process_Description: (retain if applicable, otherwise rewrite as necessary or delete step) Compilation stage - when DLG hypsography data exist, some minor editing must be performed on the data records. The purpose of the edit is to prepare a generic version of the DLG from which a raw DEM can be gridded using the following steps: (1) Import DLG hypsography data into the workstation environment, (2) remove all major attribute codes and a few extraneous minor codes from the hypsography, (3) if DLG hydrography exists, water bodies are tagged with a single elevation value with rivers and streams unattributed, (4) remove all area and node records from data files, (5) delete the bounding neatline, (6) check contour elevation attributes against the base topographic map, (7) set up the spatial parameters for the output DEM, and (8) run the grid routine to generate the raw DEM.
Source_Used_Citation_Abbreviation: HYPSO
Source_Used_Citation_Abbreviation: HYDRO
Process_Date: Unknown

Process_Step:
Process_Description: (retain if applicable, otherwise rewrite as necessary or delete step) Compilation stage - when DLG hypsography data does not exist, it is necessary to generate a hypsographic overlay from the topographic map separate. The overlay is then used for the gridding of the DEM. The process steps are as follows: (1) generate raster scan files of the topographic contours and hydrographic data from stable-based material; depending on the density of the map data, a scan resolution between 500 and 1,000 dots per inch is used; (2) import the raster scan into the workstation environment; (3) register corner ticks for the raster file to the map corner coordinates; (4) edit the raster file to clean up inconsistencies that resulted from the scan resolution or from discrepancies within the source manuscript; (5) vectorize the raster file into a

vector format; (6) process the vector file to clean up spurs and webbing that may have occurred during vectorization; (7) tag contour lines with the appropriate elevation value; (8) set up spatial parameters for the output DEM; and (9) run grid routine to generate the raw DEM.
Process_Date: Unknown
Source_Produced_Citation_Abbreviation: CONTOURS2
Source_Produced_Citation_Abbreviation: DEM

Process_Step:
Process_Description: (retain if applicable, otherwise rewrite as necessary to report on your method of editing) Water body edit - includes lakes, ponds, reservoirs, and double-line streams/rivers. Water body information is collected either during compilation or during the water body edit by one of two methods, described in the order in which they evolved. (1) During the edit stage, use the commercial software Delta3D to collect shorelines from a base topographic map with manual digitizing methods. Delta3d is used to constrain the shorelines and water bodies to the gridded surface. Water body surfaces are flattened and assigned with either a known or an estimated elevation value. (2) During compilation of the DLG hypsography overlay, water body outlines are collected as contours, and rivers and streams are collected as breaklines on a second overlay. The two overlays are merged to create a single DLG to grid the DEM.
Process_Date: Unknown
Source_Produced_Citation_Abbreviation: DEM
Source_Produced_Citation_Abbreviation: WATER BODY or CONTOURS2

Process_Step:
Process_Description: (retain if applicable, otherwise rewrite as necessary to report on your method of editing) Delta3D is used to edit and eliminate some of the anomalies created as a result of the DEM gridding. Anomalies caused by mis-tagged tops, depressions, or other mis-tagged contours are corrected in both the DLG and DEM data files. Edges, when adjoining files are available, are joined with the use of smoothing routines contained in the editing software. A final visual verification by the editor is performed using Delta3D.
Process_Date: Unknown
Source_Produced_Citation_Abbreviation: CONTOURS2
Source_Produced_Citation_Abbreviation: DEM

Process_Step:
Process_Description: A test for vertical RMSE is done with a minimum of 28 checkpoints and stored in record C, data element 5. The RMSE check value is a comparison between the final output DEM and the topographic base map. The USGS software EditDEM is used to check and edit the header record, correct illegitimate characters, clip excess elevations from outside the neatline, and fill out profiles to the neatline where elevations are absent.
Process_Date: Unknown

Source _Citation_Abbreviation: DEM

Process_Step:
Process_Description: Validation - the data file's physical format is validated with the USGS software DEM Validation System (DVS). DVS checks the format of all data records, further verifies the content of the data fields for consistency, and creates a pass/fail summary of the tests performed. DEM data are entered into the NDCDB only upon passing the DVS.
Process_Date: YYYYMM date of completion or date of revision
Source _Citation_Abbreviation: DEM

Metadata_Reference_Information:
Metadata_Date: Date metadata was submitted or revised
Metadata Contact
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: Name of contractor or cooperator
Contact_Person: Technical person that oversees process
Contact_Address:
Address_Type: mailing and physical address
Address:
City:
State_or_Province:
Postal_Code:
Contact_Voice_Telephone:
Contact_Electronic_Mail_Address:
Metadata Standard Name
Metadata Standard Version

PART 4: GLOSSARY OF TERMS

Accuracy – the closeness of an estimated (for example, measured or computed) value to a standard or accepted [true] value of a particular quantity. Note: Because the true value is not known, but only estimated, the accuracy of the measured quantity is also unknown. Therefore, accuracy of coordinate information can only be estimated.

- **Absolute Vertical Accuracy** – a measure that relates the stated elevation to the true elevation with respect to an established vertical datum. The computed value for the absolute vertical accuracy (tested, or compiled to) should be included in the metadata file.

Artifacts – Buildings, trees, towers, telephone poles or other elevated features that should be removed when depicting a DEM of the bare-earth terrain. Artifacts are not just limited to real features that need to be removed. They also include unintentional by-products of the production process, such as stripes in manually profiled DEMs. Any feature, whether man-made or system-made, that unintentionally exists in a digital elevation model.

Aspect – The compass direction, facing downward, with the steepest slope. Identifies the orientation of a surface with respect to compass direction, as well as calculates the angle of the face.

Breaklines – Linear features that describe a change in the smoothness or continuity of the surface. The two most common forms of breaklines are as follows:

- **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, as described below, by enforcing the breakline as TIN edges, but they do not define interruptions in surface smoothness. Soft breaklines are generally synonymous with **3-D breaklines** because they are depicted with series of x/y/z coordinates.

- **Hard breaklines** define interruptions in surface smoothness. They are used to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are 3-D breaklines, they are often depicted as **2-D breaklines** because features such as shorelines and building footprints are normally depicted with series of x/y coordinates only.

Calibration – Procedures used to identify systematic errors in hardware, software, and procedures so that these errors can be corrected in preparing the data derived there from.

Cartesian coordinates system - A coordinate system consisting of N straight lines(1-dimensional spaces) intersecting at one common point (the origin) and determining N distinct hyperplaces ((N-1)-dimensional spaces); the n-th ($1 \leq n \leq N$) coordinate of a point

is the distance, along the *n*-axis, from the origin to the point where that axis is intersected by the hyperplace containing that point, through the *N*-1 other axes.
or

- **2-D Cartesian coordinates** – a pair of numbers that locate a point by its distances from two intersecting, normally perpendicular lines in the same plane. Each distance is measured along a parallel to the other line. UTM and State Plane coordinates are examples of 2-D Cartesian coordinates.

- **3-D Cartesian coordinates** – a triad of numbers that locate a point by its distance from three fixed planes that intersect one another at right angles. Except for unique applications, 3-D Cartesian coordinates with *z-coordinates* are rarely used. Instead, *z-values* are more popularly understood as heights or elevations above a curved surface defined by the vertical datum, ellipsoid, or geoid.

Checkpoint – One of the points in the sample used to estimate the positional accuracy of the dataset against an independent source of higher accuracy.

Confidence level – The probability that errors are within a range of given values.

Consolidated vertical accuracy – The result of a test of the accuracy of 40 or more check points (z-values) consolidated for two or more of the major land cover categories, representing both the open terrain and other land cover categories. Computed using a nonparametric testing method (95^{th} Percentile), a consolidated vertical accuracy is always accompanied by a fundamental vertical accuracy. See fundamental and supplemental vertical accuracies.

Contour – A line connecting points of equal elevation.

Contour interval – The difference in z-values between contours.

Coordinates – A group of 3-D numbers that define a point in 3-D space. Traditionally, a vertical coordinate would be defined as a 3-D coordinate, that is, a x/y coordinate with an associated z-value

Datum – Any quantity or set of such quantities that may serve as a basis for calculation of other quantities. Herein, the term *datum* is synonymous with *geodetic datum* defined below.

Datum, Geodetic – A set of constants specifying the coordinate system used for geodetic control, i.e., for calculating coordinates of points on the Earth. At least eight constants are needed to form a complete datum: three to specify the location of the origin of the coordinate system, three to specify the orientation of the coordinate system, and two to specify the dimensions of the reference ellipsoid. (Before geocentric geodetic datums became possible, it was customary to define a geodetic datum by five quantities: the latitude and longitude of an initial point, the azimuth of a line from this point, and the two parameters of a reference ellipsoid. In addition, specification of the components of the deflection of the vertical at the initial point, or the condition that the minor axis of the ellipsoid be parallel to the Earth's axis of rotation provided two more quantities. The datum was still not complete because the origin of the coordinate system remained free to shift in one dimension. This meaning does not conform to modern usage.)

Datum, Horizontal – A geodetic datum specifying the coordinate system in which horizontal control points are located.

Datum, Tidal – A surface with a designed elevation from which heights or depths are reckoned, defined by a certain phase of the tide. A tidal datum is local, usually valid only for a restricted area about the tide gauge*(s)* used in defining the datum.

Datum, Vertical – A set of fundamental elevations to which other elevations are referred.

Digital Elevation Models (DEMs) have at least three different meanings:

- "DEM" is a generic term for digital topographic and/or bathymetric data in all its various forms. Unless specifically referenced as Digital Surface Models (DSMs), the generic DEM normally implies elevations of the terrain (bare earth z-values) void of vegetation and manmade features.

- As used by the U.S. Geological Survey (USGS), a DEM is the digital cartographic representation of the elevation of the land at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum.   As described in document, there are many types of standard USGS DEMs. Refer to section 2.5 of these guidelines.

- As used by other users in the U.S. and elsewhere, a DEM has bare earth z-values at regularly spaced intervals in x and y, but normally following alternative specifications, with narrower grid spacing and State Plane coordinates for example.

Digital Line Graphs (DLGs) – Geospatial data, digitized as node, line and area features, using hundreds of different attribute codes to define basic cartographic data categories such as hypsography (contours), hydrography, transportation, manmade features, vegetation, boundaries, survey control, etc. USGS digitizes 11 categories of cartographic features on its topographic quadrangles at various scales and archives DLGs in the NDCDB. FEMA digitizes 4 categories of cartographic features on flood hazard maps for the National Flood Insurance Program. Current data collection in all major mapping programs is directed toward producing topologically structured Level-3 DLG data, referred to as DLG-3. Other government and private sector organizations collect and produce geospatial datasets in DLG-3 format to facilitate the interchange and use of DLG data in a standard format compatible with diverse GIS software programs.

Digital Terrain Elevation Data (DTED) – Standard elevation datasets of the National Geospatial-Intelligence Agency (NGA), similar to standard USGS DEMs described above.

Digital Terrain Models (DTMs) have at least two different definitions:

- In some countries, DTMs are synonymous with DEMs, representing the bare earth terrain with uniformly spaced z-values.

- As used herein, DTMs may be identical to DEMs, but they may also incorporate the elevation of significant topographic features on the land and change points and breaklines that are irregularly spaced so as to better characterize the true shape of the bare earth terrain. The net result of DTMs is that the distinctive terrain features are more clearly defined, and contours generated from DTMs more closely approximate the real shape of the terrain. Such DTMs are normally more expensive and time consuming to produce than uniformly spaced DEMs because breaklines are ill suited for automation; but the DTM results are technically superior to standard DEMs for many applications.

Digital Surface Models (DSMs) – Similar to DEMs or DTMs, except that they depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth. DSMs are especially relevant for telecommunications management, forest management, air safety, 3-D modeling and simulation.

Elevation – The distance measured upward along a plumb line between a point and the geoid. The elevation of a point is normally the same as its orthometric height, defined as "H" in the equation: $H = h – N$.

This is the "official" geodesy definition of elevation, but the term elevation is also used more generally for height above a specific vertical reference, not always the geoid.

Elevation post – The vertical component of a DEM grid point, having height above the vertical datum equal to the z-value of its grid point.

Ellipsoid – A closed surface whose planar sections are either ellipses or circles. The Earth's ellipsoid is a biaxial ellipsoid of revolution (defined by its major axis "a" and its minor axis "b") obtained by rotating an ellipse about its minor (shorter) axis.

Ellipsoid height – The height above or below the reference ellipsoid, i.e., the distance between a point on the Earth's surface and the ellipsoidal surface, as measured along the normal (perpendicular) to the ellipsoid at the point and taken positive upward from the ellipsoid. Defined as "h" in the equation: $h = H + N$. Same as ellipsoidal height.

Fundamental vertical accuracy – The fundamental vertical accuracy is the value by which vertical accuracy can be equitably assessed and compared among datasets. The fundamental vertical accuracy of a dataset must be determined with check points located only in open terrain where there is a very high probability that the sensor will have detected the ground surface. It is obtained utilizing standard tests for RMSE. See supplemental and consolidated vertical accuracies.

Geoid – The equipotential (level) surface of the earth's gravity field that, on average, coincides with mean sea level in the open undisturbed ocean. In practical terms, the geoid is the imaginary surface where the oceans would seek mean sea level if allowed to continue into all land areas so as to encircle the earth. The geoid undulates up and down with local variations in the mass and density of the earth. The local direction of gravity is always perpendicular to the geoid.

Geodetic datum – See Datum, geodetic

Geoid height – The difference between an ellipsoid height and an orthometric height. Defined as "N" in the equation: N = h – H.

Geodetic height – See ellipsoid height.

Geospatial data – Information that identifies the geographic location and characteristics of natural or constructed features and boundaries of earth. This information may be derived from, among other things, remote sensing, mapping, and surveying technologies.

Grid – A geographic data model that represents information as an array of equally sized square cells. Each grid cell is referenced by its geographic or x/y orthogonal coordinates.

Horizontal accuracy – Positional accuracy of a dataset with respect to a horizontal datum.

Horizontal error – Magnitude of the displacement of a feature's recorded horizontal position in a dataset from its true accurate position, as measured radially and not resolved into x and y.

Horizontal post spacing – The smallest distance between two discrete points that can be explicitly represented in a gridded elevation dataset. It is important to note that features of a size equal to, or even greater than the post spacing, may not be detected or explicitly represented in a gridded model. For gridded elevation data the horizontal post spacing may be referenced as the cell size, the grid spacing, the posting interval, or the ground sample distance. Horizontal post spacing should be documented in the metadata file.

Hydro-enforcement – The removal of elevations from the tops of selected drainage structures (bridges and culverts) in a DEM, TIN or topographic dataset to depict the terrain under those structures. Also referred to as drainage enforced.

Hypsography – The configuration of land or underwater surfaces with respect to a horizontal and vertical datum. Hypsography includes topographic and bathymetric contours, spot heights, mass points, breaklines, and all forms of generic DEM data except DSMs that depict surfaces above the ground.

IFSAR – Interferometric Synthetic Aperture Radar – AN airborne or spaceborne interferometer radar system, flown aboard rotary or fixed wing aircraft or space-based platforms, that is used to acquire 3-D coordinates of terrain and terrain features that are both man-made and naturally occurring. IFSAR systems form synthetic aperture images of terrain surfaces from two spatially separated antennae over an imaged swath that may be located to the left, right, or both sides of the imaging platform.

Image correlation – A computerized technique to match the similarities of pixels in one digital image with comparable pixels in its digital stereo image to automate or semi-automate photogrammetric compilation. Image correlation provides a faster method for generating DEMs photogrammetrically, but automatic correlation normally results in DSMs instead of DEMs because such correlation generates elevations of rooftops, treetops and other surface features as imaged on the stereo photographs.

Independent source of higher accuracy – Data acquired independently of procedures to generate the dataset that is used to test the positional accuracy of a dataset. The independent source of higher accuracy shall be of the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.

Interpolation – The estimation of z-values at a point with x/y coordinates, based on the known z-values of surrounding points.

Lattice – A 3-D surface representation method created by a rectangular array of points spaced at a constant sampling interval in x and y directions relative to a common origin. A lattice differs from a grid in that it represents the value of the surface only at the "mesh points" or "elevation posts" of the lattice, rather than the value of the cell area surrounding each mesh point.

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

Mass points – Irregularly spaced points, each with an x/y location and a z-value, used to form a TIN. When generated manually, mass points are ideally chosen to depict the most significant variations in the slope or aspect of TIN triangles. However, when generated by automated methods, For example, by LIDAR or IFSAR scanners, mass point spacing and pattern depend on characteristics of the technologies used to acquire the data. Mass points are most often used to make a TIN, but not always. They can be used as XYZ point data for interpolation of a grid without an intermediate TIN stage.

Order – The accuracy ranking of one measurement or survey with respect to other measurements or surveys.

Orthometric height – The height above the geoid as measured along the plumb line between the geoid and a point on the Earth's surface, taken positive upward from the geoid

Positional accuracy – The accuracy of the position of features, including horizontal and/or vertical positions.

Post spacing – The z-values at regularly spaced intervals of a grid (the ground distance in x and y ("post spacing" = $\Delta x = \Delta y$)). The post spacing is usually specified in units of whole feet or meters. Actual grid spacing, datum, coordinate system, data format, and other characteristics may vary widely from grid to grid.

Profile – A vertical view of a surface derived by sampling surface values along a specified line. In USGS DEMs, profiles are the basic building blocks of an elevation grid and are defined as one-dimensional arrays, i.e., arrays of n columns by 1 row, where n is the length of the profile.

Puddle – One or more grid cells totally surrounded by cells of higher elevation (see also pit).

Relative Accuracy – A measure that accounts for random errors in a dataset. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors (systematic errors and blunders removed) in determining the positional orientation (For example, distance, azimuth, elevation) of one point or feature with respect to another.

Relative Vertical Accuracy – A measure of the point-to-point vertical accuracy within a specific dataset. To determine relative vertical accuracy, the vertical difference between two points is measured. That difference is then compared to the difference in elevation for the same two points on the reference. The difference between the two measures represents the relative accuracy. The reference must have at least three times the accuracy of the intended product accuracy, insuring that all systematic errors and blunders have been removed. Relative vertical accuracy, an important characteristic of elevation data used for calculating slope, should be documented in the DEM metadata file.

Resolution – In the context of gridded elevation data, resolution is related to the horizontal post spacing and the vertical precision. Other definitions include:

- The size of the smallest feature that can be represented in a surface or image.
- Sometimes used to state the number of points in x and y directions in a lattice, For example, 1201 x 1201 mesh points in a USGS one-degree DEM

Root mean square error – The square root of the mean of squared errors for a sample.

Slope – The measure of change in z-value over distance, expressed either in degrees or as a percent. For example, a rise of 4 meters over a distance of 100 meters describes a 2.3° or 4 percent slope.

Spatial data – See geospatial data.

Surface – a 3-D geographic feature represented by computer models built from uniformly- or nonuniformly-spaced points with x/y coordinates and z-values.

Supplemental vertical accuracy – The result of a test of the accuracy of z-values over areas with ground cover categories or combinations of categories other than open terrain. Obtained utilizing the 95^{th} percentile method, a supplemental vertical accuracy is always accompanied by a fundamental vertical accuracy. See fundamental and consolidated vertical accuracies.

Triangulated Irregular Networks (TINs) – A set of adjacent, nonoverlapping 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. The TIN data structure allows for the efficient generation of surface models for the analysis and display of terrain and other types of surfaces. A TIN surface can be created from one or more of the following sources: point, line and polygon data; contour maps; stereoplotter data; LIDAR, IFSAR, or Sonar data; randomly distributed points in ASCII files; breakline data; and DEM lattices. TINs usually require fewer data points than DEMs or DTMs, while capturing critical points that define terrain discontinuities and are topologically encoded so that adjacency and proximity analyses can be performed. TINs have several other advantages over DEMs and DTMs; but they are probably best known for their superiority in surface modeling, For example, calculation of slope, aspect, surface area and length; volumetric and cut-fill analysis; generation of contours; interpolation of surface z-values; generation of profiles over multiple surfaces; intervisibility analysis; and 3-D visualization, simulation, and fly-throughs.

Undulation of the geoid – The rise and fall of the geoid. Sometimes used synonymously with *geoid height*.

Vertical accuracy – Measure of the positional accuracy of a dataset with respect to a specified vertical datum.

Vertical datum – See Datum, Vertical

Vertical error – The displacement of a feature's recorded elevation in a dataset from its true or more accurate elevation.

Well-defined point – A point that represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum.

World Geodetic System 1984 (WGS 84) – WGS 84 represents the best available global geodetic reference system of the Earth for practical military applications of mapping, charting, geopositioning and navigation. The system includes a defined coordinate system, fundamental and derived constants, the geoid model (Earth Gravitational Model 1996), the ellipsoid (normal) gravity model and a list of local datum transformations.

X-coordinate – The distance along the x-axis from the origin of a 2-D or 3-D Cartesian coordinate system. An x-coordinate is the first half of UTM coordinates or the easting of State Plane coordinates.

Y-coordinate – The distance along the y-axis from the origin of a 2-D or 3-D Cartesian coordinate system. A y-coordinate is the second half of UTM coordinates or the northing of State Plane coordinates.

Z-coordinate – 1) The distance along the z-axis from the origin of a 3-D Cartesian coordinate system. 2) The elevation or height above the vertical datum.

Z-units are the units of measure used for the z-values in a geographic dataset.

Z-values are the elevations of the 3-D surface above the vertical datum at designated x/y locations.

Part 5. MAP ACCURACY STANDARDS

5.1 NATIONAL MAP ACCURACY STANDARD (NMAS)

Vertical Accuracy

Some DEM users are accustomed to referring to vertical accuracy in terms of the contour interval, normally in U.S. survey feet. The National Map Accuracy Standard (NMAS) specifies vertical accuracy in terms of the contour interval at the 90 percent confidence level as follows: "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 the NMAS is called the Vertical Map Accuracy Standard (VMAS). The NMAS became obsolete for digital mapping products because computers can easily change the scale and contour interval of a map, and maps don't get more accurate just because the computer can take 10-foot contours, for example, and regenerate 5-, 2- or 1-foot contours for higher resolution display purposes.

Horizontal Accuracy

Many users of geospatial data are accustomed to referring to horizontal accuracy in terms of the scale of a published map. The NMAS states: "Horizontal accuracy: For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than $1/30^{th}$ of an inch, measured on the publication scale: for maps on publication scales of 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only**.**" (This standard is tightened to $1/50^{th}$ of an inch for smaller-scale maps.) The $1/30^{th}$ of an inch standard for large scale maps, and $1/50^{th}$ of an inch for small 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 don't get more accurate just because the computer enables users to "zoom in" on the map to display it at a larger scale.

The NMAS is still relevant for printed maps, but not for digital maps that can be manipulated.

5.2 NATIONAL STANDARD FOR SPATIAL DATA ACCURACY (NSSDA)

Vertical Accuracy

In 1998, the Federal Geographic Data Committee (FGDC) published the National Standard for Spatial Data Accuracy (NSSDA), which superseded the NMAS for digital mapping products. Vertical Root Mean Square Error ($RMSE_z$) calculations were established, and vertical accuracy ($Accuracy_z$) at the 95 percent confidence level was established as 1.9600 x $RMSE_{z,}$ assuming that all systematic errors have been eliminated to the greatest extent possible and the errors are normally distributed. $Accuracy_z$ is defined as "the linear uncertainty value, such that the true or theoretical location of the point falls within ± of that linear uncertainty value 95-percent of the time." Note that the NSSDA specifies vertical errors at the 95 percent confidence level, whereas the NMAS specifies vertical errors at the 90 percent confidence level.

By assuming all vertical errors have a normal distribution, the NSSDA/NMAS conversion factors are as follows:

$$\mathbf{Accuracy_z = VMAS \times 1.1916}$$

Horizontal Accuracy

For horizontal accuracy, the NSSDA implemented a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data with respect to clearly defined 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 $RMSE_r$, assuming that systematic errors have been eliminated as best as possible and that the errors have a normal distribution. $Accuracy_r$ 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." As indicated above, the NSSDA specifies horizontal errors at the 95 percent confidence level, whereas the NMAS specifies horizontal errors at the 90 percent confidence level.

When assuming all horizontal errors have a normal distribution, the NSSDA/NMAS conversion factor is as follows:

$$\mathbf{Accuracy_r = CMAS \times 1.1406}$$

PART 6: REFERENCES

American Congress on Surveying and Mapping and The American Society of Civil Engineers, 1978, Definitions of Surveying and Associated Terms: American Congress on Surveying and Mapping and The American Society of Civil Engineers, 210 p.

American Society for Photogrammetry and Remote Sensing, 2001, Digital Elevation Model Technologies and Applications: The DEM Users Manual, 539 p.

Anderson, J.R., Hardy, E.E., Roach, J.T., & Witmer, R.E. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper, No. 964. USGS, Washington, D.C. The classification list is available online at: http://landcover.usgs.gov/pdf/anderson.pdf

Bureau of the Budget, 1947, *National Map Accuracy Standards*, Office of Management and Budget, Washington, D.C.

Defense Mapping Agency, 1981, Department of Defense Glossary of Mapping, Charting and Geodetic Terms: Washington, D.C., Defense Mapping Agency, 203 p.

FGDC, 2000, Content Standard for Digital Geospatial Metadata Workbook, Version 2.0, 122 pp. Federal Geographic Committee, c/o USGS, Reston, VA

FGDC, 1998, FGDC Content Standard for Digital Geospatial Metadata, version 2, FGDC-STD-001-1998, 71 pp. [http://www.fgdc.gov/metadata/contstan.html].

FGDC, 2002, Content Standard for Digital Geospatial Metadata: Extensions for Remote Sensing Metadata (Final Draft), 147pp. Federal Geographic Data Committee, c/o USGS, Reston, VA, http://www.fgdc.gov/standards/status/csdgm_rs_ex.html

FGDC, 1998, *Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy*, Federal Geographic Data Committee, c/o/ USGS, Reston, VA, This document is available online at: www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf.

National Geodetic Survey, 1986, Geodetic Glossary: Washington, D.C., U.S. Government Printing Office, 273 p.

NGA TR 8350.2, Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems, Third Edition, January 2000. http://164.214.2.59/GandG/pubs.html

NLCD Land Cover Class Definitions. U.S. Geological Survey. Accessed May 7, 2004. http://landcover.usgs.gov/classes.asp

NOAA, 1997, NOAA Technical Memorandum NOS NGS-58, *Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)*, National Oceanic and Atmospheric Administration, Silver Spring, MD.