American National Standard
for Information Technology—

Geographic Information Framework – Draft Data Content Standards For Digital Elevation

American National Standard
for Information Technology

Geographic Information Framework
Draft Data Content Standards
For Digital Elevation

(Part XXX)

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Note to Commenters: Although this working draft is presented as a stand-alone standard in ANSI format, it is intended to become part of a single, harmonized NSDI Framework Data Content Standard. In all, five transportation subthemes and seven Framework themes will be harmonized into one standard for presentation to the InterNational Committee on Information Technology Standards, Geographic Information Systems[1]*. Structural and formatting changes are likely to occur to this and other working drafts during the harmonization process. While editorial comments are welcome on this and any working draft, standards development would benefit most, at this time, from comments on scientific and technical issues. The single, harmonized draft will also be made available for public review and comment.*

To comment on working drafts, please use the Microsoft Excel spreadsheet located at http://www.geo-one-stop.gov/Standards/index.html. Only comments received in this format will be considered. You can email comments to GeospatialComments@geo-one-stop.gov., or mail them to the following address:

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Arlington, VA 22201

[1] See the diagram, "Nested Relationship of NSDI Framework Data Content Standard Harmonization" at the end of this document.

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1 Scope, Purpose, and Application

The concept of the Geospatial One Stop requires that the data adhere to certain standards. This content standard defines the elements that permit collection and exchange of digital elevation data consistent with the National Spatial Data Infrastructure's (NSDI) framework for elevation data. This standard includes a conceptual schema expressed in the Unified Modeling Language (UML) according to ISO 19109 – Rules for Application Schema. The conceptual schema conforms to the ISO 19109 normative references and documentation of all features, attributes, and relationship definitions (see Annex A).

This standard identifies the content elements required for digital elevation data to be used for the Geospatial One Stop but leaves other aspects of the data, such as structures for data interchange, to market forces. For example, the standard requires that elevations be expressed in decimal meters; yet, decisions about file-format are left to market forces. Collecting and sharing NSDI digital elevation data that are consistent with the Geospatial One Stop content standard will assure the user community accurate and reliable access to the data. Furthermore, the principles described in this standard may be extended to other geographic entities to facilitate the exchange of other geospatial thematic data.

2 Referenced and Related Publications

The following standards contain provisions, which through reference in this text constitute provisions of this DRAFT American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

- American Society for Photogrammetry and Remote Sensing, October 2001, *Digital Elevation Model Technologies and Applications: The DEM Users Manual*
- *Data Content Standard for Digital Land Elevation* (FGDC draft withdrawn January 1999)
- FGDC-STD-001-1998, *Content Standard for Digital Geospatial Metadata (version 2.0)*
- FGDC-STD-012-2002, *Content Standard for Digital Geospatial Metadata: Extensions for Remote Sensing Metadata*
- FGDC-STD-007.3-1998, *Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy*
- ISO Standard 19123 – *Schema for Coverage Geometry and Functions* (Draft at Committee Stage, April 2003)
- ISO Standard 19115 – *Metadata* (Draft at Publication Stage, April 2003)
- National Digital Elevation Program, *Guidelines for Digital Elevation Data* (Draft, April 2003)
- Open GIS Consortium, *Abstract Specification of the Open GIS Consortium*

3 Definitions

Absolute accuracy – A measure that accounts for all systematic and random errors in a data set. Absolute accuracy is stated with respect to a defined datum or reference system.

Absolute horizontal accuracy – A measure of the positional quality of data with respect to a horizontal reference datum.

Absolute vertical accuracy – A measure that relates the stated elevation to the true elevation with respect to an established vertical datum.

Accuracy – The closeness of an estimated (e.g., measured or computed) value to a standard or accepted [true] value of a particular quantity. Note that because the true value is not certain, but only estimated, the accuracy of the measured quantity is also not certain. Therefore, accuracy of coordinate information can only be estimated.

Artifacts – Any feature, whether natural, manmade, or system-made that unintentionally exists in digital elevation data. Artifacts may include evidence of real surface features such as buildings, trees, towers, telephone poles or other elevated features that are not completely removed when producing bare-earth elevation data. They may also include unintentional by-products of the production process, such as stripes in manually profiled elevation data.

> **Break lines** – Strings of X, Y coordinates used to model a linear change in the slope or continuity of a terrain surface. Break lines may be modeled using two-dimensional or three-dimensional line modeling techniques. Two-dimensional break lines are used to represent breaks in the terrain along lines of constant elevation such as water body shorelines and footprints of buildings on level terrain. They cannot be used to model linear terrain breaks that trend up or down slopes. Three-dimensional break lines allow the Z-value to vary for each X,Y coordinate and are typically used to model gentle to abrupt surface breaks that trend up or down slope. However, they can also be used to model terrain breaks of constant elevation. Three-dimensional break lines may be use to model features such as stream banks, water body shorelines, dams, sharp or gentle ridges, and footprints of buildings on sloping terrain.

Contour – A line connecting points of equal elevation. Contours are typically modeled as a single elevation attribute associated with a string of (X,Y) values.

Contour interval – The difference in elevation between contours.

Coordinates – A set of numbers that determines the location of a point within a defined spatial reference system. Coordinates as used in this standard may refer to a two-dimensional horizontal position defined by X, Y coordinates, or a three-dimensional position defined by X, Y, and Z (elevation) values.

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.

Discrete grid – A three-dimensional surface representation method created by a rectangular array of points spaced at a uniform sampling interval in x and y directions relative to a common origin. A discrete grid represents the value of the surface only at the grid points or elevation posts of the grid, rather than the value of the cell area surrounding each grid point.

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.

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 point in an elevation grid, having height above the vertical datum equal to the z-value assigned to the 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: $h = H + N$, where H = orthometric height and N = geoid height. Same as ellipsoidal height.

Geodetic datum – See datum, geodetic.

Geoid – That equipotential (level) surface of the Earth's gravity field, which, 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.

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

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

Grid points – The uniformly spaced points in a grid. Grid points are located at a constant interval in x and y directions relative to a common origin, and contain the z-values for the surface at each discrete location.

Horizontal accuracy – The 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.

Hydro-enforcement – The removal of elevations from the tops of selected drainage structures (bridges and culverts) in a DEM, TIN or topographic dataset in order to depict the terrain under those structures. Also referred to as drainage enforcement. Hydro-enforcement may also include removal of false depressions, enhanced depiction of stream channels, water body flattening, and smoothing of stream slope.

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.

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 – These types of discrete points are usually represented by a collection of irregularly, or non-uniformly organized points. Each point is identified by a coordinate pair, (X,Y), and an elevation value (Z). While mass points are not necessarily presented in a uniform or structured pattern, they often are

acquired in a systematic distribution, which is intended to facilitate accurate representation of the surface or features the data are intended to model. When generated manually, mass points are ideally chosen so that subtle terrain characteristics, such as gradual variations in slope or aspect, or distinct features such as a levee or a river embankment are adequately represented in the data. However, when generated automatically, such as through the use of an active sensing system (LIDAR), mass point distribution depends upon the characteristics of the sensors used to acquire the data, and their performance in different terrain, and land cover types.

Orthometric height (elevation)– 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. Defined as "H" in the equation: H = h – N, where h = ellipsoid height and N = geoid height.

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

Post spacing – Also: horizontal post spacing, elevation post spacing. The measured distance between discrete grid points along the rows and columns of a grid-based elevation model. For elevation grids the horizontal post spacing may be referenced as the cell size, the grid spacing, the posting interval, horizontal resolution, or the ground sample distance. Horizontal post spacing should be documented in the metadata file.

Relative accuracy – A measure that accounts for random errors in a data set. 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 (e.g., distance, azimuth, elevation) of one point or feature with respect to another.

Relative horizontal accuracy – A measure of the point-to-point horizontal accuracy within a specific data set. To determine relative horizontal accuracy, the horizontal distance between two points is measured and then compared to the corresponding measure on the reference. The difference between the two distances represents the relative accuracy. As with absolute accuracy, it may be more meaningful to report the relative horizontal accuracy of the source material.

Relative vertical accuracy – A measure of the point-to-point vertical accuracy within a specific data set. 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 is an important characteristic of elevation data used for calculating slope.

Resolution – In the context of this standard, resolution is defined by the horizontal post spacing and the vertical precision of a grid-based elevation model. Because elevation data can be resampled from mass points to grids or from high-resolution grids to low-resolution grids, it is important to distinguish between dataset resolution and the resolving capabilities of the sensor or collection system. In its purest sense resolution is the measure of the size of the smallest feature that can be faithfully represented in a model of a surface and is a function of the collection system's capability for distinguishing unique features both horizontally and vertically. It is important to note, however, that a grid-based elevation model with a post spacing of a given value, may or may not faithfully represent, or resolve, all features of that given size.

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% slope.

Surface – A three-dimensional geographic feature represented by computer models built from uniformly, or non-uniformly spaced points with x/y coordinates and z-values.

Three-dimensional line models – Vector data models containing strings of horizontal (X,Y) coordinates; each coordinate is associated with its own elevation. This method of modeling can be used to depict contours, break lines of constant elevation, and break lines of varying elevation.

Two-dimensional line models – Vector data models containing strings of horizontal (X,Y) coordinates; each coordinate string is associated with a single elevation. This method of modeling terrain features may be used to depict contour lines or two-dimensional break lines.

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

Vertex (vertices) – A point joining two line segments and defined by two- or three-dimensional coordinates.

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

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

Vertical precision – The smallest vertical increment that can be represented in the data. This may also be referred to as vertical resolution.

Void areas – Locations in an elevation coverage where no elevation data are available.

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

Z-values – The elevations above the vertical datum at designated x/y locations in a three-dimensional surface.

4 General Data Requirements

4.1 Introduction

Geographic phenomena fall into two broad categories, discrete and continuous. While the actual terrain surface for any particular geographic area is a continuous surface it is typically modeled using discrete elevation samples in the form of grids, points, or lines.

This standard models framework digital elevation data as discrete coverages. This standard uses the term "coverage," adopted from the Abstract Specification of the Open GIS Consortium [1], to refer to any data representation that assigns values directly to spatial position. This section identifies the general requirements to be applied to any framework elevation coverages produced under this standard.

4.2 Data Models

Framework digital elevation data shall be modeled within the context of three subclasses of discrete coverages: georeferenced grids, points, or lines. Grid-, point-, and line-coverage specifications, defined in this standard, accommodate the level of content and relationships necessary for exchange of all forms and formats of these data in a predictable and repeatable manner.

Definitions for, and characteristics of, framework digital elevation data may be specific to these individual data models, or they may apply to all three data models. Characteristics, which apply to all three data models, are presented as general requirements, and characteristics pertaining to individual data models are subsequently discussed in model-specific sections of this standard.

4.3 Datums

4.3.1 Horizontal Datum

NAD 83 shall be the default horizontal datum for all framework digital elevation datasets for the United States and its territories. The official horizontal datum of the United States for civil applications is the North American Datum of 1983 (NAD 83), which is based on the Geodetic Reference System of 1980 (GRS 80) ellipsoid. When first introduced, NAD 83 was intended to be nearly identical to the World Geodetic System of 1984 (WGS 84). However, recent evidence suggests that NAD 83 is non-geocentric by about 2.25 meters, while the latest version of WGS 84 is geocentric to a few centimeters. WGS 84 is the official horizontal datum of the United States for military applications. NAD 83 replaced the North American Datum of 1927 (NAD 27), which was based on the Clarke 1866 Ellipsoid. NAD 27 was not a geocentric datum; its initial point was at Meades Ranch in Kansas.

4.3.2 Vertical Datum

NAVD 88 shall be the default vertical datum for all framework digital elevation datasets for the United States and its territories. The official vertical datum of the United States for civil applications is the North American Vertical Datum of 1988, which has only a single tidal gauging station (Father Point/Rimouski at the mouth of the St. Lawrence River in Quebec, Canada). NAVD 88 replaced the National Geodetic Vertical Datum of 1929 (NGVD 29), often referred to (erroneously) as "mean sea level", which constrained 26 gauge sites (along Atlantic, Pacific, and Caribbean coasts) at mean sea level of zero elevation. Rather than being the same (zero) elevations, these 26 sites actually have different elevations relative to each other, a major reason why NGVD 29 had to be replaced in both the U.S. and Canada. Other significant errors are contained in NGVD 29, yielding discrepancies with NAVD 88 that can vary quickly over short distances and can exceed 2 meters.

4.4 Coordinate System and Units

Horizontal coordinates (X,Y) shall be represented as seconds of arc in longitude and latitude, respectively. Longitude for the western hemisphere shall be expressed as negative arc seconds. The geographic coordinate system is superior to rectangular Cartesian systems for this standard because it enables seamless coverage of broad geographic areas and simplifies transformation and projection to local coordinate systems.

Elevation (Z) values shall be orthometric heights expressed in decimal meters.

4.5 Reference Ellipsoid and Geoid

When collecting new framework elevation data, the latest geoid model shall be used for all surveys that involve GPS and the metadata for any digital elevation dataset shall identify the geoid model that was used.

Elevations produced by conventional surveys are orthometric heights, which are based on the rules of gravity. Orthometric heights are measured up from the geoid (the surface of equal gravity potential which best fits mean sea level globally) along the plumb line to the surface of the Earth.

Elevations produced by GPS surveys (including LIDAR and IFSAR controlled by airborne GPS) are ellipsoid heights, which are based on the rules of geometry. GPS measures vectors that are independent of the local direction of gravity.

The difference between the orthometric height and ellipsoid height at any location is equal to the geoid height which also equals the "undulation of the geoid" at that location, i.e., the distance of the geoid above or below the mathematical ellipsoid at that location.

In order to accurately convert elevations from GPS surveys into traditional orthometric heights (such as for NAVD88), 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, e.g., GEOID93, GEOID96, GEOID99, etc. To improve the accuracy of an old survey using a newly released geoid model it is important to know which geoid corrections (GEOID99 or GEOID96) were applied to the original data. 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-effects in any DEM that crosses the border.

4.6 Data Quality

4.6.1 Accuracy

Framework elevation data accuracy shall employ the National Standard for Spatial Data Accuracy (NSSDA), which implements a statistical and testing methodology for estimating the positional accuracy of points in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. Data producers shall ensure that all critical components have known accuracies suitable for the construction of elevation data, and that those accuracies are reported in the metadata.

This reporting methodology provides a common language for reporting positional accuracy so that users can evaluate data sets for fitness of use for their applications. The NSSDA uses root-mean-square error (RMSE) to estimate positional error. RMSE is then used to calculate and report accuracy in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the data set will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

The NSSDA does not define threshold accuracy values. Users are encouraged to establish thresholds for their product specifications and applications and for contracting purposes. Data producers may elect to use accuracy thresholds in standards such as the National Map Accuracy Standards of 1947 (U.S. Bureau of the Budget, 1947) or Accuracy Standards for Large-Scale Maps [American Society for Photogrammetry and Remote Sensing (ASPRS) Specifications and Standards Committee, 1990] if they decide that these values are applicable to their digital geospatial data accuracy requirements. However, accuracy of new or revised data products will be reported according to the NSSDA.

4.6.1.1 Absolute and Relative Horizontal Accuracy

Absolute horizontal accuracy is a measure of the positional (planimetric) quality of data with respect to a reference datum. The ability to directly test the absolute horizontal accuracy of a dataset is related to the data spacing. As the spacing between elevation samples increases, horizontal accuracy testing becomes less reliable. It is difficult to measure the horizontal accuracy of discrete elevation data, because terrain features are generalized in the surface and the terrain lying between samples is not represented. *For this reason, reporting of horizontal accuracy of the source material (imagery or map) from which the data were produced, or alternatively, reporting of a "compiled to meet" accuracy value derived through sensor tests or other means is strongly recommended.*

Reporting of the relative horizontal accuracy of framework elevation data is not required. Relative horizontal accuracy is a measure of the point-to-point horizontal accuracy within a specific data set. To determine relative horizontal accuracy, the horizontal distance between two points is measured and then compared to the corresponding measure on the reference. The difference between the two distances represents the relative accuracy. As with absolute accuracy, it may be more meaningful and practical to report the relative horizontal accuracy of the source material.

4.6.1.2 Absolute and Relative Vertical Accuracy

A record of the absolute vertical accuracy of framework elevation data is required. Absolute vertical accuracy is a measure that relates the stated elevation to the true elevation with respect to an established vertical datum. "True" elevation values must have at least three times the accuracy of the elevation data being tested.

While a measure of the relative accuracy of framework elevation data is not required, it is often very helpful for determining the suitability of the data for various applications. Relative vertical accuracy is a measure of the point-to-point vertical accuracy within a specific data set. 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.

4.6.2 Vertical Precision

Though no requirements exist for vertical precision, the Z units should be precise enough to retain the vertical accuracy reported for the data. The vertical precision is the smallest vertical increment that can be represented in the data. This may also be referred to as vertical resolution. Vertical precision should not be confused with vertical accuracy. Adjacent elevation values may differ by as little as one unit of measure (the vertical precision), but this does not imply that the individual elevation posts are accurate to that increment of measure.

5 Model-Specific Requirements

This section describes specific requirements for each of the elevation framework data models – grids, points, and lines.

5.1 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 data models. A regular spacing of elevations requires that only one point be referenced to a horizontal ground position. From this point, in conjunction with coordinate referencing information supplied with the grid, the horizontal location of all other points can be determined. This eliminates the need to explicitly define the horizontal coordinates of each elevation and minimizes file size. The grid is also an efficient structure for data processing.

The spacing within the grid can be chosen to most efficiently represent the size and frequency of terrain undulations to be modeled. For example, rough or dissected terrain may require a narrow grid spacing, while gentle relief may be adequately modeled with a fairly wide grid spacing. Grids may not model all terrain features smaller or narrower than the post spacing when the feature lies between grid samples.

In a geographic-coordinate grid ?x represents "? longitude" and ?y represents "? latitude" rather than specified ground distances. One second of longitude and one second of latitude 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 (see Figure 1). 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 grid dimensions may be different in order to approximate uniform intervals of ground distance in both dimensions.

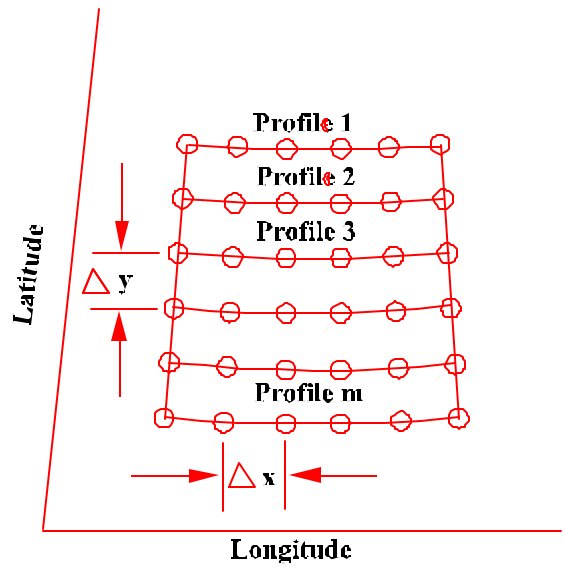


Figure 1 – Example of an Arc-Second Grid Structure

Specific requirements of the framework grid coverage are as follows:

- The grid origin (row 1, column 1) shall be the upper left corner and the grid data shall be row-major order (within a row, columns are ordered from left to right).
- Within a specified coverage, all rows shall be comprised of an equal number of samples and all columns shall be comprised of an equal number of samples.
- All horizontal coordinates of the grid posts shall be evenly divisible by the post-space interval.
- All grid points within the coverage shall be populated with Z-values representing either actual elevations or "null" values. The numeric code representing the null value shall be documented in the metadata.

5.2 Points

Points are the most basic data model used for modeling terrain and bathymetric surfaces. Commonly referred to as mass points, this type of discrete coverage is usually represented by a collection of irregularly, or non-uniformly organized points. Each point is explicitly identified by a coordinate pair (X,Y) and an elevation value (Z). While mass points are not necessarily presented in a uniform or

structured pattern, they often are acquired in a systematic distribution, which is intended to facilitate accurate representation of the surface or features the data are intended to model. When generated manually, mass points are ideally chosen so that subtle terrain characteristics, such as gradual variations in slope or aspect, or distinct features such as a levee or river embankment are adequately represented in the data. However, when generated automatically, such as through the use of an active sensing system (LIDAR), mass point distribution depends upon the characteristics of the sensor used to acquire the data, and its performance in different terrain and land cover types.

Specific requirements of the framework point coverage are as follows:

- The positions of all elevation samples shall be explicitly represented within the dataset as X, Y, Z triplets.
- Points may be assigned attributes in addition to the requisite horizontal and vertical reference (X,Y,Z). Attribution could include identification as a control point, reference to the type of surface to which the point applies, or other characteristics specific to the point. The order (if applicable) and definition of these additional attributes must be specified in the metadata.

5.3 Lines

This standard allows the use of only three-dimensional line-modeling techniques within line coverages. Three-dimensional line modeling supports the exchange of all common types of constant-elevation and variable-elevation line features, including: contours, cross sections (or transects), and break lines. Although two-dimensional modeling techniques are more efficient for lines of constant elevation, they are precluded from this standard to keep the framework elevation requirements simple as possible.

Contours are lines connecting points of equal elevation. Contours are a common visual representation of topography and bathymetry in mapping applications.

Cross sections, or transects, are lines that connect points of varying elevation values. They are used for specialized applications to represent a string of elevations along a designated path. Cross sections, which are generally perpendicular to a linear terrain feature, are used for a variety of engineering applications. For example, a cross section of a stream will show the stream channel geometry above and below the water surface for hydraulic engineering purposes and a cross section of a road will show the shape of the road surface including its crown, shoulders, and ditches.

Break lines are lines that model a change in the slope or continuity of a surface. Break lines may represent surface breaks observed at a constant elevation or that trend up and down slope.

Specific requirements for discrete line coverages are as follows:

- Each line shall consist of one or more straight line segments.
- Three dimensional (X,Y,Z) coordinates shall be used to define the end points and vertices of the lines.
- Start- and end-points of a line shall be identified.
- Attributes may be assigned to individual line segments or to entire lines. The order (if applicable) and definition of these additional attributes must be specified in the metadata.

6 Elevation Data Source

This section describes various methods for producing framework elevation data. Although these sources are the most common, other methods exist that may be suitable for production of framework data.

6.1 Cartographic Sources

Cartographic source includes any mapped information that provides elevations at known geographic positions or that helps improve the shape of the elevation surface.

6.1.1 Hypsographic Features

Contour lines on existing topographic maps may be digitized as vector lines (strings of x/y coordinates) with elevation attributes. Grid data models may be produced by interpolating, at regular intervals, between the vectorized contours.

6.1.2 Hydrographic Features

Shorelines of rivers, lakes and other hydrographic features may be digitized as vector break lines between the water surface and the ground surrounding water. Small stream centerlines, drainage ditches, and other hydrographic features may also be represented with break lines. Such break lines, when combined with contour lines, are used to enforce the gradient and depiction of rivers and streams in elevation models.

6.1.3 Transportation Features

Roads, railroads, and bridges may also be digitized as vector break lines for improving the representation of transportation related terrain features in the elevation model.

6.2 Passive Remote Sensing Sources

6.2.1 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, elevation data has been compiled photogrammetrically from stereo aerial photography. The vertical accuracy of photogrammetrically derived elevations is dependent on many variables including the flying height and focal length of the mapping camera used.

6.2.2 Satellite Imagery

Satellite imagery, also illuminated by the sun, may be used to photogrammetrically compile elevation data. Because the vertical accuracy of such elevation data is still a function of the flying height and equivalent focal length of the mapping camera, elevation data derived from satellite imagery are generally restricted to accuracies of 5 meters or worse.

6.3 Active Remote Sensing Sources

6.3.1 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 three-dimensional coordinates of terrain and terrain features that are both manmade 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. C-band and X-band IFSARs, including the Shuttle Radar Topography Mission (SRTM), are used to map the top surfaces of terrain features in production of digital surface models (DSMs). Although not yet proven in practice, the new P-band IFSARs are designed to penetrate vegetation in order to map the bottom, bare-earth terrain features. IFSAR systems operate both day and night and are generally "all weather" systems that penetrate cloud cover.

6.3.2 Light Detection and Ranging (LIDAR)

Airborne LIDAR uses an instrument, flown aboard rotary or fixed wing aircraft, that measures distance to a reflecting object by emitting timed pulses of laser light and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to distance. With topographic LIDAR systems, first-return LIDAR pulses are used to map the top surfaces of terrain features for creating DSMs; and last-return LIDAR pulses are used to map the bottom, bare-earth terrain features for creating digital terrain models (DTMs). Airborne LIDAR bathymetry (ALB) systems use two different lasers to measure the depth beneath the water surface; but 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.

6.3.3 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 or surface. The term is applied principally to an apparatus that itself generates the sound; the object or surface then reflects or scatters the sound back to the apparatus.

6.4 Mobile Survey Platforms

6.4.1 GPS Real Time Kinematic (RTK)

Real time kinematic GPS uses 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.

6.4.2 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, including elevations of river bottoms below the water level.

7 Elevation Data Content

This section describes common surface types and surface treatments for framework elevation data. Each of these surface characteristics that apply to a set framework data shall be documented in metadata.

7.1 Surface Types

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

7.1.1 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 and 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 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.

7.1.2 Digital Terrain Model (DTM) or Bare Earth

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.

7.1.3 Bathymetric Surface

The bathymetric surface represents the submerged surface of underwater terrain.

7.1.4 Topographic/Bathymetric Surface (Topo/Bathy)

This surface type represents an integration of both topographic surfaces and bathymetric surfaces. This provides a continuous surface through the land water interface, avoiding the discontinuity generally found between elevation data representing these surfaces. The source of the discontinuities between topographic elevation data and bathymetric elevation data result from the use of disparate reference systems. Bringing both the topographic and bathymetric source data to a common reference system – principally to an ellipsoidal reference – produces this surface. The ellipsoid-referenced data then may be transformed to an orthometric reference through application of the appropriate geoid model. For framework topo/bathy data, the reference datum would be NAVD88, and NAD83.

7.1.5 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 manmade 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.

7.1.6 Point Cloud

A point cloud elevation data set is generally a raw data set containing three-dimensional point samples, i.e., single points with multiple elevations. An example of a point cloud file would be a LIDAR multi-return data set.

7.2 Surface Treatments

The intended application of an elevation model typically dictates the particular terrain features represented and how those features are 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 surface types presented in section 7.1, although useful for general discussion, define only broad categorizations of elevation surface characteristics. Merely specifying a bare-earth DTM or reflective surface DSM does not sufficiently define how all terrain features are represented in the DEM surface. For example, specifying a bare-earth surface almost always implies that elevations on buildings and vegetation have been removed but it does not necessarily imply that overpasses and bridges are removed from the surface.

7.2.1 Hydrography

Some degree of hydrographic enforcement, performed to depict the flow of water in digital elevation models, may be necessary when remote sensing systems capture manmade structures or irregularities in the terrain such as 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; enforcing the gradient of rivers, streams, and narrow drains; removal of manmade structures that actually impede the flow of water (buildings) or of other structures that only appear to impede the flow of water (bridges and overpasses); and draining or filling of artificial depressions that fail to depict natural surface flow of water. Each of these topics is further explained in the following sections. Hydro-enforcement is also explained in the introductory chapter of ASPRS, 2001.

7.2.1.1 Water Bodies

Water bodies should be depicted with constant elevation, provided that currents and other physical forces do not significantly alter the water surface. Ponds, lakes and reservoirs are assigned their known or estimated elevations, and their shorelines may be treated as break lines with constant elevation. Oceans 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 actual physical situation that mean sea level equates to different elevations along different coastlines because of variations in ocean topography, currents, and winds. The horizontal position and shape of shorelines is normally determined from digital orthophotos or other georeferenced image source.

7.2.1.2 Rivers and Streams

Rivers and streams 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 both shorelines are normally determined from digital orthophotos or other georeferenced image source. These shorelines are also treated as break lines 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 break lines that delineate the double shorelines. Elevations are then linearly interpolated for each shoreline vertex between the discrete points. These shoreline break lines are now three-dimensional break lines in which the elevation gradually decreases from the upstream contour elevation to the downstream contour elevation. 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, several alternative methods may be used to estimate the water elevations at various locations along the stream. 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 the shorelines as three-dimensional break lines with elevations that decrease in the downstream direction.

7.2.1.3 Narrow Drains

When continuous down stream drainage is desirable, narrow drainage channels may be enforced by a single three-dimensional break line. Break line enforcement in this situation ensures that no false dams or depressions are represented in the model. These false features commonly occur in elevation surfaces captured or represented by randomly or uniformly spaced discrete points. A drainage break line, captured as described in section 7.2.1.2 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.

7.2.2 Manmade Structures

7.2.2.1 Buildings

For a bare-earth DEM, elevation points on buildings 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, a DSM, which retains building elevations, may be preferable.

7.2.2.2 Bridges and Overpasses

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

7.2.2.3 Culverts

Drainage through small culverts is typically not depicted in elevation models. For some large-scale hydrographic 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.

7.2.3 Special Earthen Features

7.2.3.1 Sinkholes

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

7.2.3.2 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 manmade bridges and depict the stream surface below the bridge.

7.2.4 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% of the artifacts may take 90% 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. At a minimum, a description of the types and prevalence of known data artifacts should be provided in the metadata.

7.2.5 Completeness

7.2.5.1 No-Data Areas: Intentional/Unintentional

Specific information needs to be provided by the data provider that explains whether incomplete elevation data is intentional or unintentional. Some indication must be provided outside of the data model (for example in a metadata description or polygon) that describes where these areas are in the elevation deliverable. For both intentional and unintentional no-data areas within a grid, a false elevation (null value = - 9999) shall be assigned to identify grid posts without a valid elevation. Examples of intentional no-data areas are areas outside the project extent, areas of sensitive information such as military bases, or large bodies of water on DEM tiles that are deliberately not collected. Unintentional no-data areas are those where high winds or pilot or navigation errors cause gaps between adjoining strips or where the collection process may have malfunctioned.

7.2.5.2 Suspect Areas

Suspect areas are areas of elevations for which there is a relatively low degree of confidence. They are areas where the data producer questions whether the elevations compiled or sensed represent the intended surface. *Some indication must be provided outside of the data model (for example in a metadata description or polygon) that describes where these areas are in the elevation coverage.*

8 Metadata Samples

8.1 Metadata – Elevation Grid Coverage

```
IDENTIFICATION_INFORMATION

  Citation:
    Citation_Information:
      Originator: Two Guys Mapping
      Publication_Date: 20030415
      Title: Flood County Lidar Grid
      Geospatial_Data_Presentation_Form:
      Publication_Information:
        Publication_Place: City, State
        Publisher: Two Guys Mapping

  Description:
    Abstract:
      This geographic elevation grid was produced from a Lidar-derived TIN
      surface, which was bare-earth edited to remove points on man-made
      structures and vegetation.  The grid was interactively edited to ensure
      flattened water bodies and continuous hydrographic flow along streams.
    Purpose:
      To create a hydro-enforced elevation model for hydrologic and hydraulic
      modeling purposes.
```

```
  Time_Period_of_Content:
    Time_Period_Information:
      Range_of_Dates/Times:
        Beginning_Date: March 2002
        Ending_Date: April 2002
    Currentness_Reference: Ground condition
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: As needed
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -76.000000
      East_Bounding_Coordinate: -75.500000
      North_Bounding_Coordinate: 36.500000
      South_Bounding_Coordinate: 36.000000
  Keywords:
    Theme:
      Theme_Keyword_Thesaurus: None
      Theme_Keyword: DEM
      Theme_Keyword: DTM
      Theme_Keyword: Elevation
      Theme_Keyword: Height
      Theme_Keyword: Lidar
      Theme_Keyword: Hydrographic surface
      Theme_Keyword: elevation grid
  Access_Constraints:  None
  Use_Constraints: None


DATA_QUALITY_INFORMATION

  Attribute_Accuracy:
    Attribute_Accuracy_Report: N/A
  Logical_Consistency_Report: N/A
  Completeness_Report:
      Data is complete for hydrologic and hydraulic analysis for drainage
      areas within Flood County. Elevations in areas of dense mangrove have
      been interpolated from surrounding ground elevations and should be
      considered suspect (i.e., do not necessarily meet the reported vertical
      accuracy for the dataset.)  Refer to “Flood County suspect elevations
      image” at www.2guysmapping.com for location of suspect areas.  Water
      elevations beyond 200 meters of the coastline are assigned null
      elevation values = -9999.
  Positional_Accuracy:
    Horizontal_Positional_Accuracy:
      Horizontal_Positional_Accuracy_Report:
      Compiled to meet 5.2 feet horizontal accuracy at 95% confidence level
      using 30 test points. Test points were created by GPS and terrestrial
      methods not exceeding second order standards of 20 PPM or less.
    Vertical_Positional_Accuracy:
      Vertical_Positional_Accuracy_Report:
      Tested 1.2 feet vertical accuracy at 95% confidence level in open
      terrain using 30 test points.  Test points were collected according to
      guidelines for 5cm local network accuracy at the 95 percent confidence
      level established in NOS NGS-58, "Guidelines for Establishing GPS-
      Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)".
  Lineage:
```

```
Source_Information:
  Source_Citation:
    Citation_Information:
      Originator: Two Guys Mapping
      Publication_Date: 20020615
      Title: Flood County Lidar
      Geospatial_Data_Presentation_Form: model
      Publication_Information:
        Publication_Place: City, State
        Publisher:
  Source_Scale_Denominator:
  Type_of_Source_Media:
  Source_Time_Period_of_Content:
    Time_Period_Information:
      Range_of_Dates/Times:
        Beginning_Date: 20020330
        Ending_Date: 20020401
    Source_Currentness_Reference: ground condition
  Source_Citation_Abbreviation:
  Source_Contribution: Lidar collection and processing
Process_Step 1:
  Process_Description:
  Lidar points were collected for Flood County using sensor referenced
  GPS and IMU in flight collection and simultaneous ground GPS
  collection.  Elevation mass points were generated from LIDAR data.
  Lidar collection and processing information includes:
        1. Max PDOP allowed during LIDAR data collection:  7.0
        2. Max distance from GPS ground stations at data collection: 60km
        3. Flight height: 3,250 feet, nominal AGL
        4. Swath Width: 18 degrees from nadir (36 degrees total swath)
        5. Distance between flight lines: 50% sidelap (200% coverage)
        6. Type of Scanner: ZZ-Topo 1000
        7.  Calibration: Surveyed airport locations before each flight
        8.  Number of scanner returns per pulse: Four
        9.  Nominal ground sample distance:  6 feet
        10. Data processing:
              Points were referenced to ground through rigorous
              adjustments using sensor GPS/IMU data and ground GPS data
              using proprietary software. Ellipsoid heights were
              converted to orthometric heights using GEOID99. A TIN was
              produced from the bare-earth mass points using ArcInfo, v.
              8.1.2.
  Source_Used_Citation_Abbreviation:
  Process_Date: 20020715

Source_Information:
  Source_Citation:
    Citation_Information:
      Originator: Flood County, NC
      Publication_Date: 20000201
      Title: Flood County maps
      Geospatial_Data_Presentation_Form: map
      Publication_Information:
        Publication_Place: City, State
        Publisher: Flood County
  Source_Scale_Denominator: 4800
  Type_of_Source_Media: paper
```

```
        Source_Time_Period_of_Content: 19990301
          Source_Currentness_Reference: ground condition
        Source_Citation_Abbreviation:
        Source_Contribution: Horizontal positions of hyrographic features
      Process_Step 2:
        Process_Description:
        Points over manmade structures and vegetation were removed through
        automated and manual processes to create a bare-earth surface.  The TIN
        produced from the Lidar bare-earth points was modified using additional
        breaklines, horizontally delineated from 1:4800 scale county maps, to
        enforce stream and water body shoreline locations and continuous stream
        flow.  Elevations for the breaklines were interpolated from nearby
        Lidar points.  Points on bridge and overpass surfaces were replaced
        with approximated stream channel elevations. A geographic grid was then
        produced from the TIN using ArcInfo v. 8.1.2.  A final review and edit
        was performed on the grid to ensure proper hydrographic feature
        representation.
        Source_Used_Citation_Abbreviation:
        Process_Date: 20020715


SPATIAL_DATA_ORGANIZATION_INFORMATION

  Direct_Spatial_Reference_Method: Raster
  Raster_Object_Information:
    Cell_Value_Type: Signed 16-bit integer
    Raster_Object_Type: Point
    Row_Count: 16,201
    Column_Count: 16,201
    Vertical_Count: 1

SPATIAL_REFERENCE_INFORMATION

  Horizontal_Coordinate_System_Definition:
    Geographic:
      Latitude_Resolution: 0.001
      Longitude_Resolution: 0.001
      Geographic Coordinate_Units: Arc-seconds
    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: 0.001
      Altitude_Distance_Units: Meters
      Altitude_Encoding_Method:
            Explicit elevation included with horizontal coordinates
  Georeferencing_Information:
    Georectified_Raster:
      Pixel_Resolution:
      Grid_First_Element:
        Grid_First_Element_Map_X_Coordinate: -273600.000
        Grid_First_Element_Map_Y_Coordinate: 131400.000
```

```
      Grid_Orientation:
        Row_Delta_X: 0.111111
        Row_Delta_Y: 0.000000
        Column_Delta_X: 0.000000
        Column_Delta_Y: 0.111111
      Point_Position_In_Pixel: N/A
      Storage_Order: Row major


ENTITY_AND_ATTRIBUTE_INFORMATION

  Detailed_Description:
    Entity_Type:
      Entity_Type_Label:
      Entity_Type_Definition:
      Entity_Type_Definition_Source:

DISTRIBUTION_INFORMATION

  Distributor:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: Two Guys Mapping
        Contact_Person: Guy One
      Contact_Position: Mapping Manager
      Contact_Address: City, State
        Address_Type: Mailing
        Address: 605 Street Rd.
        City: City
        State_or_Province: State
        Postal_Code: 55555
        Country: United States
      Contact_Voice_Telephone: 555-555-5555
      Contact_Facsimile_Telephone:
      Contact_Electronic_Mail_Address: guy1@2guysmapping.com
      Hours_of_Service: 8-5 M-F
  Resource_Description: Digital file format only.
  Distribution_Liability:
  Standard_Order_Process:
    Digital_Form:
      Digital_Transfer_Information:
        Format_Name: ARC Export
      Digital_Transfer_Option:
        Offline_Option:
          Offline_Media: CD-ROM
          Recording_Format:
          Compatibility_Information:
    Ordering_Instructions:

METADATA_REFERENCE_INFORMATION

  Metadata_Date: 20030401
  Metadata_Review_Date:
  Metadata_Contact:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: Two Guys Mapping
```

```
          Contact_Person: Guy Two
        Contact_Position: Distribution Manager
        Contact_Address: City, State
          Address_Type: Mailing
          Address: 605 Street Rd.
          City: City
          State_or_Province: State
          Postal_Code: 55555
          Country: United States
        Contact_Voice_Telephone: 555-555-5555
        Contact_Facsimile_Telephone:
        Contact_Electronic_Mail_Address: guy2@2guysmapping.com
        Hours_of_Service: 8-5 M-F
    Metadata_Standard_Name:
        1) FGDC Content Standards for Digital Geospatial Metadata
        2) FGDC Content Standards for Digital Geospatial Metadata: Extensions
        for Remote Sensing Metadata
    Metadata_Standard_Version:
        1) FGDC-STD-001-1998
        2) FGDC-STD-012-2002
```

8.2 Metadata – Elevation Point Coverage

IDENTIFICATION_INFORMATION

```
    Citation:
      Citation_Information:
        Originator: Two Guys Mapping
        Publication_Date: 20030415
        Title: Flood County Lidar Mass Points
        Geospatial_Data_Presentation_Form:
        Publication_Information:
          Publication_Place: City, State
          Publisher: Two Guys Mapping

    Description:
      Abstract:
        This mass-point dataset contains variably spaced discrete points with
        elevation values for Flood County, NC. These points are represented as
        X,Y,Z values in an ASCII file.  The points define the locations of
        elevation samples collected by a Lidar sensor.  This dataset has been
        bare-earth edited to remove points on man-made structures and
        vegetation.  The dataset has also been edited to ensure flattened water
        bodies and continuous hydrographic flow along streams.
      Purpose:
        To create a hydro-enforced elevation model for hydrologic and hydraulic
        modeling purposes.
    Time_Period_of_Content:
      Time_Period_Information:
        Range_of_Dates/Times:
          Beginning_Date: March 2002
          Ending_Date: April 2002
      Currentness_Reference: Ground condition
    Status:
      Progress: Complete
      Maintenance_and_Update_Frequency: As needed
    Spatial_Domain:
```

```
      Bounding_Coordinates:
        West_Bounding_Coordinate: -76.000000
        East_Bounding_Coordinate: -75.500000
        North_Bounding_Coordinate: 36.500000
        South_Bounding_Coordinate: 36.000000
    Keywords:
      Theme:
        Theme_Keyword_Thesaurus: None
        Theme_Keyword: DEM
        Theme_Keyword: DTM
        Theme_Keyword: Elevation
        Theme_Keyword: Height
        Theme_Keyword: Lidar
        Theme_Keyword: Hydrographic features
        Theme_Keyword: Mass points
    Access_Constraints:  None
    Use_Constraints: None


  DATA_QUALITY_INFORMATION

    Attribute_Accuracy:
      Attribute_Accuracy_Report: N/A
    Logical_Consistency_Report: N/A
    Completeness_Report:
        Data is complete for hydrologic and hydraulic analysis for drainage
        areas within Flood County except in areas of dense mangrove. Flow and
        connectivity for hydraulics have been tested.
    Positional_Accuracy:
      Horizontal_Positional_Accuracy:
        Horizontal_Positional_Accuracy_Report:
        Compiled to meet 5.2 feet horizontal accuracy at 95% confidence level
        using 30 test points. Test points were created by GPS and terrestrial
        methods not exceeding second order standards of 20 PPM or less.
      Vertical_Positional_Accuracy:
        Vertical_Positional_Accuracy_Report:
        Tested 0.98 feet vertical accuracy at 95% confidence level in open
        terrain using 30 test points.  Test points were collected according to
        guidelines for 5cm local network accuracy at the 95 percent confidence
        level established in NOS NGS-58, "Guidelines for Establishing GPS-
        Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)".
    Lineage:
      Source_Information:
        Source_Citation:
          Citation_Information:
            Originator: Two Guys Mapping
            Publication_Date: 20020615
            Title: Flood County Lidar
            Geospatial_Data_Presentation_Form:
            Publication_Information:
              Publication_Place: City, State
              Publisher:
        Source_Scale_Denominator:
        Type_of_Source_Media:
        Source_Time_Period_of_Content:
          Time_Period_Information:
            Range_of_Dates/Times:
```

```
            Beginning_Date: 20020330
            Ending_Date: 20020401
        Source_Currentness_Reference: ground condition
      Source_Citation_Abbreviation:
      Source_Contribution: Lidar collection and processing
    Process_Step 1:
      Process_Description:
      Lidar points were collected for Flood County using sensor referenced
      GPS and IMU in flight collection and simultaneous ground GPS
      collection.  Elevation mass points were generated from LIDAR data.
      Lidar collection and processing information includes:
            1. Max PDOP allowed during LIDAR data collection:  7.0
            2. Max distance from GPS ground stations at data collection: 60km
            3. Flight height: 3,250 feet, nominal AGL
            4. Swath Width: 18 degrees from nadir (36 degrees total swath)
            5. Distance between flight lines: 50% sidelap (200% coverage)
            6. Type of Scanner: ZZ-Topo 1000
            7.  Calibration: Surveyed airport locations before each flight
            8.  Number of scanner returns per pulse: Four
            9.  Nominal ground sample distance:  6 feet
            10. Data processing:
                  Points were referenced to ground through rigorous
                  adjustments using sensor GPS/IMU data and ground GPS data.
                  Ellipsoid heights were converted to orthometric heights
                  using GEOID99. A TIN was produced from the bare-earth mass
                  points using ArcInfo v. 8.1.2.
      Source_Used_Citation_Abbreviation:
      Process_Date: 20020715

    Source_Information:
      Source_Citation:
        Citation_Information:
          Originator: Flood County, NC
          Publication_Date: 20000201
          Title: Flood County maps
          Geospatial_Data_Presentation_Form: map
          Publication_Information:
            Publication_Place: City, State
            Publisher: Flood County
      Source_Scale_Denominator: 4800
      Type_of_Source_Media: paper
      Source_Time_Period_of_Content: 19990301
        Source_Currentness_Reference: ground condition
      Source_Citation_Abbreviation:
      Source_Contribution: Horizontal positions of hyrographic features
    Process_Step 2:
      Process_Description:
      Points over manmade structures and vegetation were removed through
      automated and manual processes to create a bare-earth surface.  The TIN
      produced from the Lidar bare-earth points was modified using additional
      breaklines, horizontally delineated from 1:4800 scale county maps, to
      enforce stream and water body shoreline locations and continuous stream
      flow.  Points on bridge and overpass surfaces were replaced with
      approximated stream channel elevations.
      Source_Used_Citation_Abbreviation:
      Process_Date: 20020715
```

SPATIAL_DATA_ORGANIZATION_INFORMATION

```
  Direct_Spatial_Reference_Method: Point
  Point_and_Vector_Object_Information:
    SDTS_Terms_Description:
      SDTS_Point_and_Vector_Object_Type: Point
      Point_and_Vector_Object_Count: 5,287,004
```

SPATIAL_REFERENCE_INFORMATION

```
  Horizontal_Coordinate_System_Definition:
    Geographic:
      Latitude_Resolution: 0.001
      Longitude_Resolution: 0.001
      Geographic Coordinate_Units: Arc-seconds
    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: 0.001
      Altitude_Distance_Units: Meters
      Altitude_Encoding_Method:
      Explicit elevation included with horizontal coordinates
```

ENTITY_AND_ATTRIBUTE_INFORMATION

```
  Detailed_Description:
    Entity_Type:
      Entity_Type_Label:
      Entity_Type_Definition:
      Entity_Type_Definition_Source:
```

DISTRIBUTION_INFORMATION

```
  Distributor:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: Two Guys Mapping
        Contact_Person: Guy One
      Contact_Position: Mapping Manager
      Contact_Address: City, State
        Address_Type: Mailing
        Address: 605 Street Rd.
        City: City
        State_or_Province: State
        Postal_Code: 55555
        Country: United States
      Contact_Voice_Telephone: 555-555-5555
      Contact_Facsimile_Telephone:
      Contact_Electronic_Mail_Address: guy1@2guysmapping.com
      Hours_of_Service: 8-5 M-F
```

```
  Resource_Description: Digital file format only.
  Distribution_Liability:
  Standard_Order_Process:
    Digital_Form:
      Digital_Transfer_Information:
        Format_Name: ASCII (X,Y,Z order)
      Digital_Transfer_Option:
        Offline_Option:
          Offline_Media: CD-ROM
          Recording_Format:
          Compatibility_Information:
    Ordering_Instructions:

METADATA_REFERENCE_INFORMATION

  Metadata_Date: 20030401
  Metadata_Review_Date:
  Metadata_Contact:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: Two Guys Mapping
        Contact_Person: Guy Two
      Contact_Position: Distribution Manager
      Contact_Address: City, State
        Address_Type: Mailing
        Address: 605 Street Rd.
        City: City
        State_or_Province: State
        Postal_Code: 55555
        Country: United States
      Contact_Voice_Telephone: 555-555-5555
      Contact_Facsimile_Telephone:
      Contact_Electronic_Mail_Address: guy2@2guysmapping.com
      Hours_of_Service: 8-5 M-F
  Metadata_Standard_Name:
      FGDC Content Standards for Digital Geospatial Metadata
  Metadata_Standard_Version: FGDC-STD-001-1998
```

8.3 Metadata – Elevation Line Coverage

```
IDENTIFICATION_INFORMATION

  Citation:
    Citation_Information:
      Originator: Two Guys Mapping
      Publication_Date: 20030415
      Title: Flood County Elevation Breaklines
      Geospatial_Data_Presentation_Form: Model
      Publication_Information:
        Publication_Place: City, State
        Publisher: Two Guys Mapping

  Description:
    Abstract:
      This breakline dataset models major hydrographic features within Flood
      County, NC. Breaklines are linear features that describe a change in
      the slope or continuity of a surface. Breaklines in this dataset 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 within
        this dataset are three-dimensional, i.e., each line end point or
        internal vertex is positioned using x, y, z coordinates.  These
        breaklines were compiled using stereo photogrammetric procedures.
      Purpose:
        To create a hydro-enforced elevation model for hydrologic and hydraulic
        modeling purposes.
    Time_Period_of_Content:
      Time_Period_Information:
        Range_of_Dates/Times:
          Beginning_Date: March 2001
          Ending_Date: April 2001
      Currentness_Reference: Ground condition
    Status:
      Progress: Complete
      Maintenance_and_Update_Frequency: As needed
    Spatial_Domain:
      Bounding_Coordinates:
        West_Bounding_Coordinate: -76.000000
        East_Bounding_Coordinate: -75.500000
        North_Bounding_Coordinate: 36.500000
        South_Bounding_Coordinate: 36.000000
    Keywords:
      Theme:
        Theme_Keyword_Thesaurus: None
        Theme_Keyword: DEM
        Theme_Keyword: DTM
        Theme_Keyword: Elevation
        Theme_Keyword: Height
        Theme_Keyword: Photogrammetry
        Theme_Keyword: Hydrographic features
        Theme_Keyword: Break line
    Access_Constraints:  None
    Use_Constraints: None


  DATA_QUALITY_INFORMATION

    Attribute_Accuracy:
      Attribute_Accuracy_Report:
        Attributes describing the breakline feature were determined through
        photo interpretation.
    Logical_Consistency_Report: Topologically clean (ArcInfo v. 8.1.2)
    Completeness_Report:
        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:
        Tested 15.2 feet horizontal accuracy at 95% confidence level using 30
        test points. Test points were created by GPS and terrestrial methods
        not exceeding second order standards of 20 PPM or less.
```

```
      Vertical_Positional_Accuracy:
        Vertical_Positional_Accuracy_Report:
        Tested 1.18 feet vertical accuracy at 95% confidence level in open
        terrain using 30 test points.  Test points were collected according to
        guidelines for 5cm local network accuracy at the 95 percent confidence
        level established in NOS NGS-58, "Guidelines for Establishing GPS-
        Derived Ellipsoid Heights (Standards: 2 cm and 5 cm)".
    Lineage:
      Source_Information:
        Source_Citation:
          Citation_Information:
            Originator: Two Guys Mapping
            Publication_Date: 20020615
            Title: Flood County aerial photography
            Geospatial_Data_Presentation_Form:
            Publication_Information:
              Publication_Place: City, State
              Publisher: Two Guys Mapping
        Source_Scale_Denominator: 6,000
        Type_of_Source_Media: diapositive
        Source_Time_Period_of_Content:
          Time_Period_Information:
            Range_of_Dates/Times:
              Beginning_Date: 20000330
              Ending_Date: 20000401
          Source_Currentness_Reference: ground condition
        Source_Citation_Abbreviation:
        Source_Contribution:
      Process_Step 1:
        Process_Description:
        Digital images were produced by scanning the source photography at a
        resolution of 15-microns. Horizontal and vertical control points were
        derived from field and aerotriangulation procedures. 3-D breaklines
        were derived through softcopy-stereo compilation methods on a Seesit-
        Drawsit softcopy stereo system. Principal breaklines were captured for
        ridges and general terrain breaks, stream centerline and top of stream
        banks.
        Source_Used_Citation_Abbreviation:
        Process_Date: 20020715

SPATIAL_DATA_ORGANIZATION_INFORMATION

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

SPATIAL_REFERENCE_INFORMATION

    Horizontal_Coordinate_System_Definition:
      Geographic:
        Latitude_Resolution: 0.001
        Longitude_Resolution: 0.001
        Geographic Coordinate_Units: Arc-seconds
      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: 0.001
        Altitude_Distance_Units: Meters
        Altitude_Encoding_Method:
        Explicit elevation included with horizontal coordinates

ENTITY_AND_ATTRIBUTE_INFORMATION

    Detailed_Description:
      Entity_Type:
        Entity_Type_Label: breaklines
        Entity_Type_Definition:
        3-D lines defining linear breaks in terrain continuity or slope
        Entity_Type_Definition_Source:
        National Digital Elevation Program - Guidelines
      Attribute:
        Attribute_Label: Streambank
        Attribute_Definition: Top of stream bank
        Attribute_Definition_Source:
        Attribute_Domain_Values:
      Attribute:
        Attribute_Label: Ridge
        Attribute_Definition: Highest line of elevation along a linear crest
        Attribute_Definition_Source:
        Attribute_Domain_Values:
      Attribute:
        Attribute_Label: Drain
        Attribute_Definition: Lowest line of elevation along a linear channel
        Attribute_Definition_Source:
        Attribute_Domain_Values:
      Attribute:
        Attribute_Label: Surface-break
        Attribute_Definition: General break in terrain surface continuity
        Attribute_Definition_Source:
        Attribute_Domain_Values:
    Overview_Description:
      Entity_and_Attribute_Overview:
      Entity_and_Attribute_Detail_Citation:

DISTRIBUTION_INFORMATION

    Distributor:
      Contact_Information:
        Contact_Organization_Primary:
          Contact_Organization: Two Guys Mapping
          Contact_Person: Guy One
        Contact_Position: Mapping Manager
        Contact_Address: City, State
          Address_Type: Mailing
          Address: 605 Street Rd.
          City: City
```

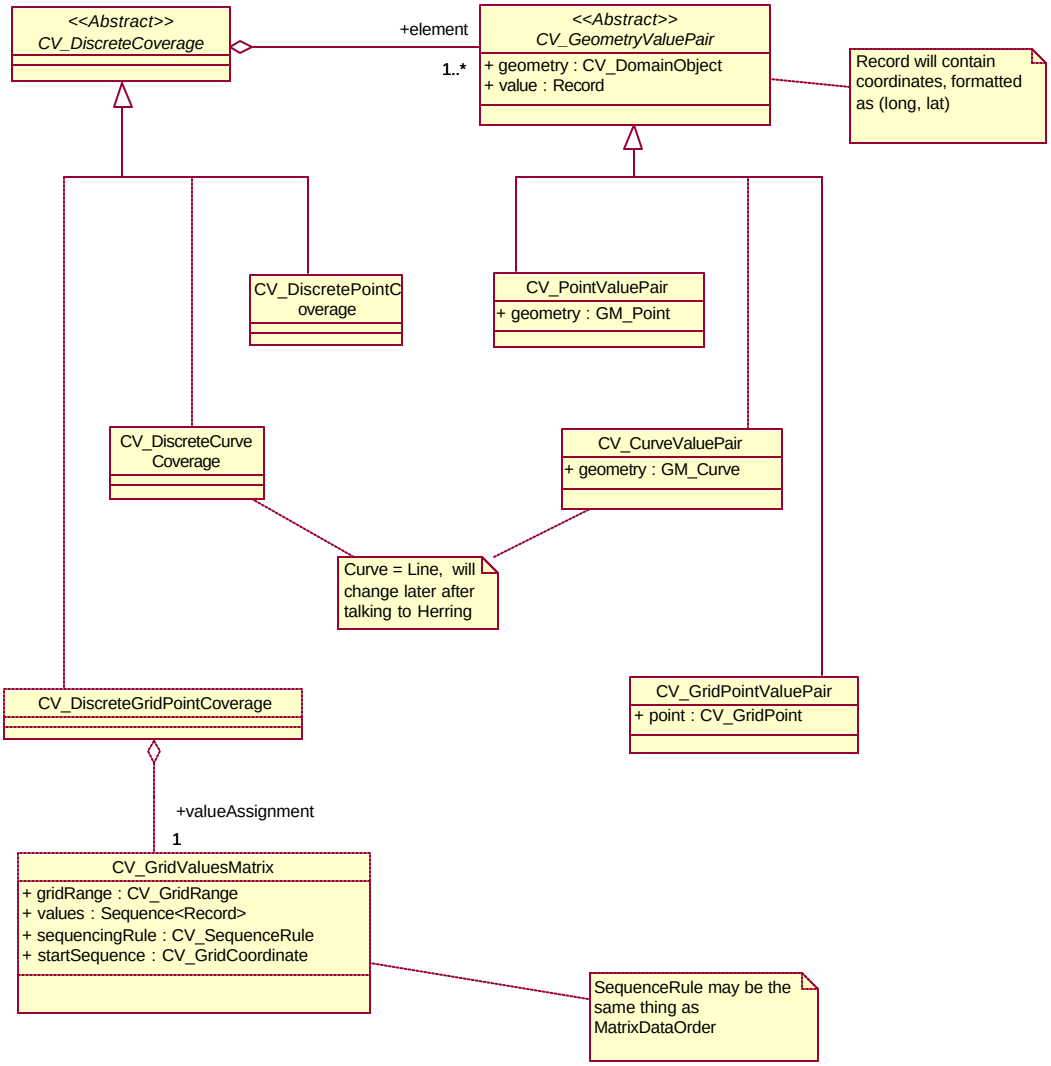
```
          State_or_Province: State
          Postal_Code: 55555
          Country: United States
        Contact_Voice_Telephone: 555-555-5555
        Contact_Facsimile_Telephone:
        Contact_Electronic_Mail_Address: guy1@2guysmapping.com
        Hours_of_Service: 8-5 M-F
    Resource_Description: Digital file format only.
    Distribution_Liability:
    Standard_Order_Process:
      Digital_Form:
        Digital_Transfer_Information:
          Format_Name: ARC Export
        Digital_Transfer_Option:
          Offline_Option:
            Offline_Media: CD-ROM
            Recording_Format:
            Compatibility_Information:
      Ordering_Instructions:

METADATA_REFERENCE_INFORMATION

    Metadata_Date: 20030401
    Metadata_Review_Date:
    Metadata_Contact:
      Contact_Information:
        Contact_Organization_Primary:
          Contact_Organization: Two Guys Mapping
          Contact_Person: Guy Two
        Contact_Position: Distribution Manager
        Contact_Address: City, State
          Address_Type: Mailing
          Address: 605 Street Rd.
          City: City
          State_or_Province: State
          Postal_Code: 55555
          Country: United States
        Contact_Voice_Telephone: 555-555-5555
        Contact_Facsimile_Telephone:
        Contact_Electronic_Mail_Address: guy2@2guysmapping.com
        Hours_of_Service: 8-5 M-F
    Metadata_Standard_Name:
        FGDC Content Standards for Digital Geospatial Metadata
    Metadata_Standard_Version: FGDC-STD-001-1998
```

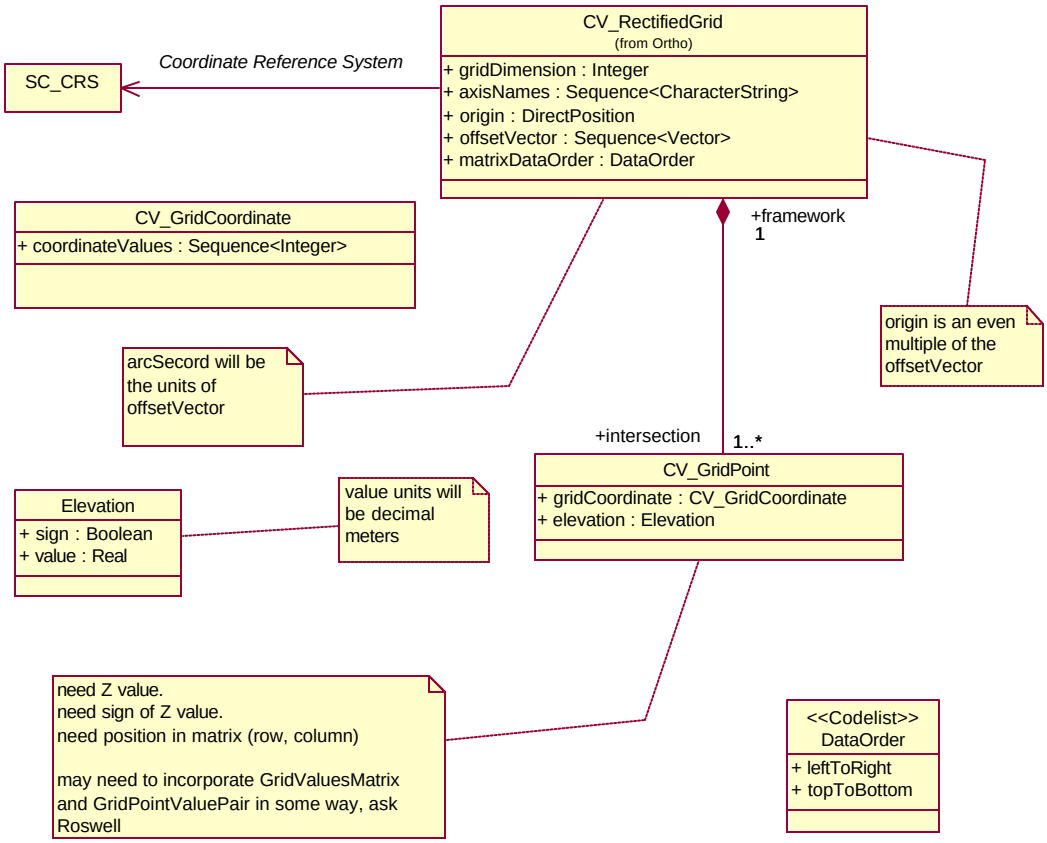
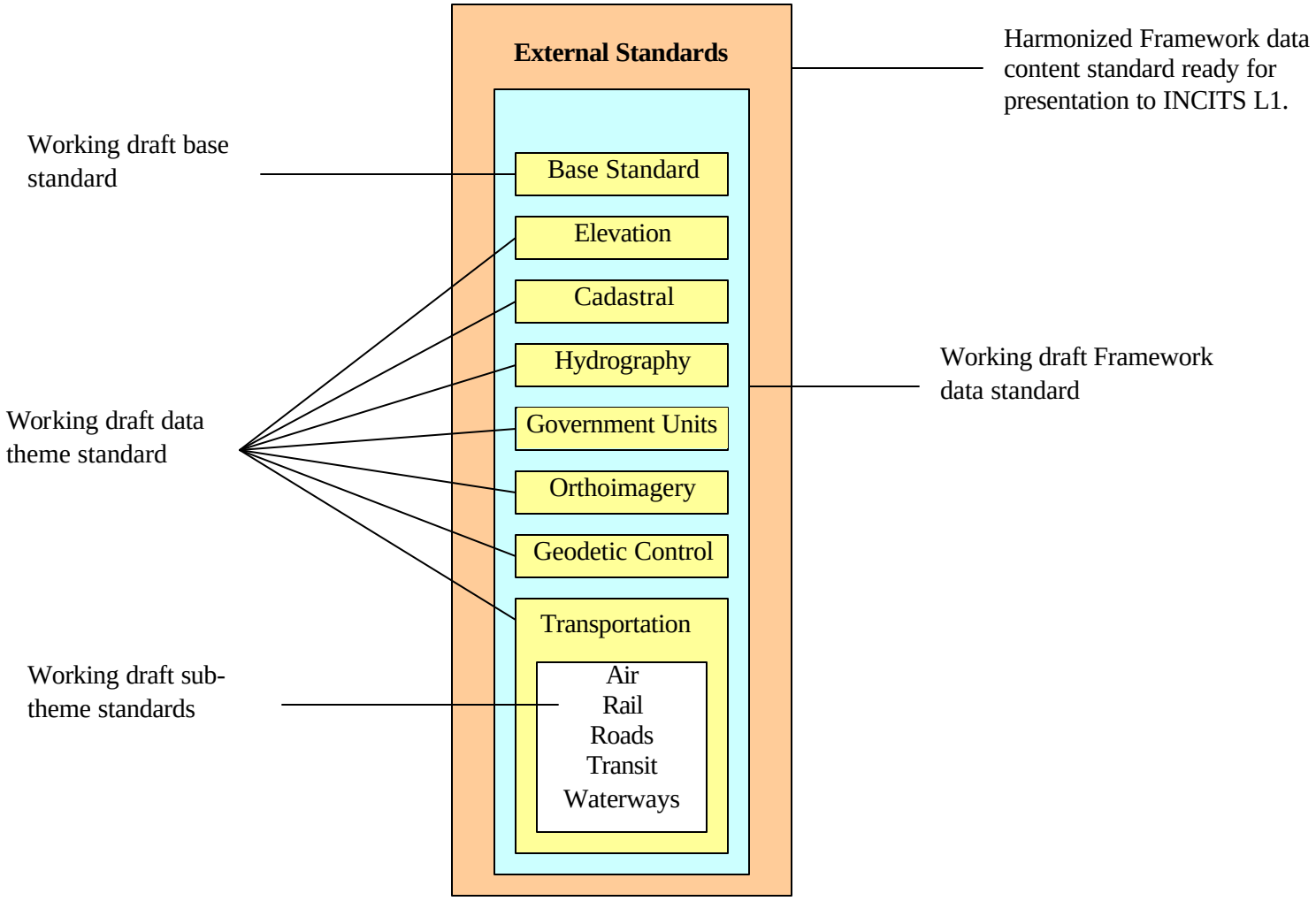
9 Maintenance Authority

The U.S. Department of the Interior, United States Geological Survey (USGS), holds primary responsibility for the elevation theme of the National Spatial Data Infrastructure, defined in OMB Circular A-16. The USGS Geography Discipline is the maintenance authority for the Standards for Digital Elevation Data in support of the Geospatial One Stop, E-Government initiative. Address questions concerning this standard to: Associate Director for Geography, USGS, Mail Stop 516, 12201 Sunrise Valley Drive, Reston, VA 20192.

Annex A
(normative)

UML Model




CV_RectifiedGrid
(from Ortho)
+ gridDimension : Integer
+ axisNames : Sequence<CharacterString>
+ origin : DirectPosition
+ offsetVector : Sequence<Vector>
+ matrixDataOrder : DataOrder
Coordinate Reference System
SC_CRS
CV_GridCoordinate
+ coordinateValues : Sequence<Integer>
+framework
1
origin is an even multiple of the offsetVector
arcSecord will be the units of offsetVector
+intersection
1..*
CV_GridPoint
+ gridCoordinate : CV_GridCoordinate
+ elevation : Elevation
Elevation
+ sign : Boolean
+ value : Real
value units will be decimal meters
need Z value.
need sign of Z value.
need position in matrix (row, column)
may need to incorporate GridValuesMatrix and GridPointValuePair in some way, ask Roswell
<<Codelist>>
DataOrder
+ leftToRight
+ topToBottom

Nested Relationship of NSDI Framework Data Content Standard Harmonization