National Mapping Program
Technical Instructions

Standards for Digital Elevation Models

Open-File Report 86-004

Department of the Interior
U.S. Geological Survey
National Mapping Division

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National Mapping Program
Technical Instructions

Part 1
General

Standards for Digital Elevation Models

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FIGURES

1. GENERAL

1.1 OBJECTIVES

The U.S. Geological Survey has been designated as the lead Federal agency for the collection and distribution of digital cartographic data. The standards specified in this document pertain to the collection, processing, and quality control of digital elevation model (DEM) data intended for entry into the National Digital Cartographic Data Base (NDCDB).

These standards are intended to facilitate the interchange and use of DEM data. DEM collection and editing systems must produce data which are compatible with other production systems not only within the Federal sector but also within other government and private sector organizations. Due to rapidly changing technologies in the mapping industries, these DEM standards cover a broad range of collection systems and related accuracy levels. It is not the intent of this standard to inhibit usage of any procedure, but to set common standards which will allow data to be acceptable for entry into the NDCDB.

This document also provides the NDCDB manager and the quality control unit(s) within the USGS with standards for testing of DEM data. Data generated by NMD production units are collected according to the standards set forth in this document. DEM data collected by other Federal agencies, or acquired through procurement from the private sector, will be accepted for entry to the NDCDB after verification according to these same standards.

1.2 SERIES DESCRIPTION

The U.S. Geological Survey produces one primary type of DEM data set referred to as 7.5-minute DEM data. These data correspond in coverage to the standard 1:24,000-scale 7.5- x 7.5-minute quadrangles. These data are available only for quadrangles in the United States.

A standard 7.5-minute DEM has the following characteristics:

- The data consist of a regular array of elevations referenced in the Universal Transverse Mercator (UTM) coordinate system.

- Elevations are in meters or feet referenced to mean sea level.

- The unit of coverage is the 7.5-minute quadrangle. Overedge coverage is not provided.

- The data are ordered from south to north in profiles that are ordered from west to east.

- The data are stored as profiles in which the spacing of the elevations along and between each profile is 30 meters. The horizontal position of the points and profiles shall be defined by integer multiples of 30 meters, i.e., coordinate values are evenly divisible by 30, computed from an origin of x = 0, y = 0.

- The profiles do not always consist of the same number of elevations due to the variable angle between true north and grid north of the UTM coordinate system.

The profiles for 7.5-minute DEM's are generated using the UTM Cartesian coordinate system as a base. The profiles are clipped between the points at which they intersect straight lines connecting the four geographic map corners. The resulting area of coverage for the DEM is a quadrilateral. The UTM coordinates of the DEM's four corners (bounds) are listed in the header record and the UTM coordinates of the starting points of each profile are listed in the profile records. These coordinates describe the shape of the quadrilateral and the variable x,y starting position of each profile. Because of the variable orientation of the quadrilateral, in relation to the UTM coordinate system, profiles intersect the east and west neatlines as well as the north and south neatlines. The intersections result in a regular stair-stepped arrangement of the 30-meter cells just inside the neatline. (See figure 1-1 for a diagram of a standard DEM.)

The DEM file structure provides for other reference systems, point spacing, irregular arrays, elevation units, and overedge coverage. However, only the standard options described above are used for 7.5-minute DEM data resident in the NDCDB.

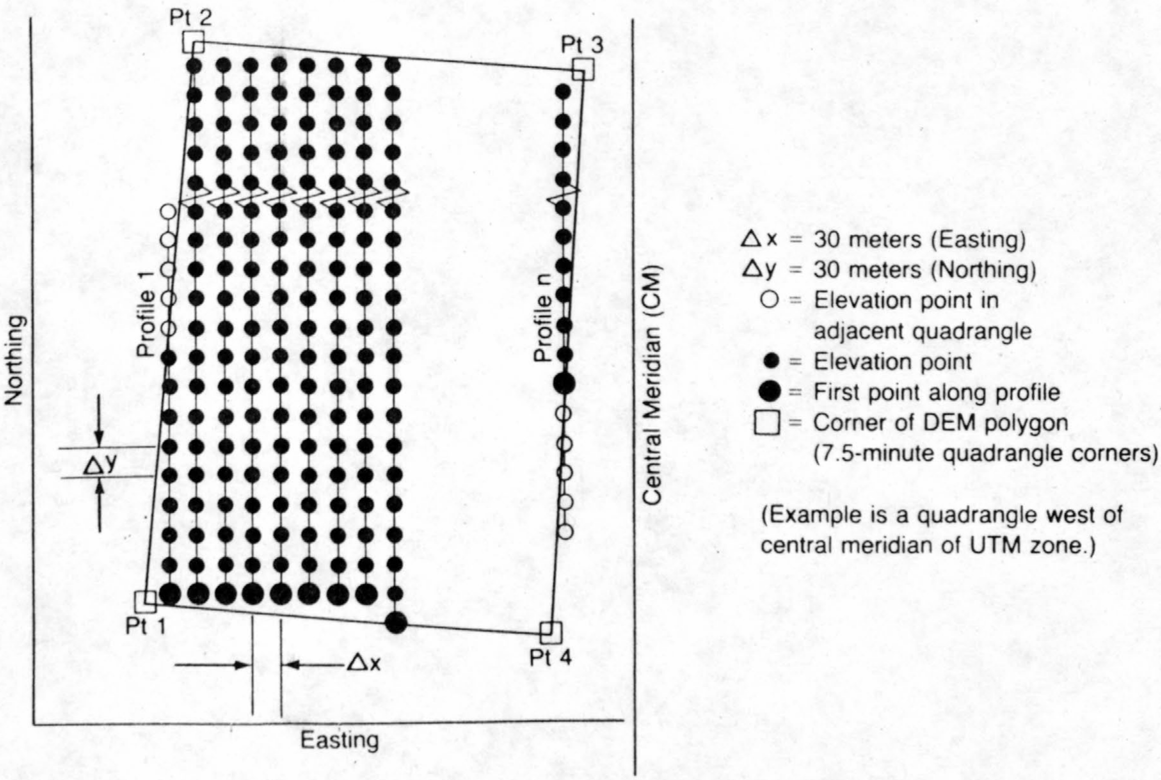

Figure 1-1 Structure of a 7.5-minute Digital Elevation Model.

1.3 SOURCES

The 7.5-minute DEM data are typically derived by digitizing elevations either from map contour overlays or from photographs taken at an average height of 40,000 feet above ground (1:80,000 scale) for the National High-Altitude Photography (NHAP) interagency program. Larger-scale photography may be used on a limited project basis. The production procedures and instrumentation used for collection of raw elevation data vary depending on production systems available to each mapping center, other agencies, or contractors. However some procedures are specified in this standard which critically affect the criteria for acceptance of data into the NDCDB. Those system dependent procedures critical to the final product standards are discussed in Part 3, Collection of Elevation Data.

Appendix 1-A: References

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De Gree, M. and McCausland, R.G., 1985, "Digital Elevation Model Image Display and Editing." In International Symposium on Computer-Assisted Cartography, Auto-Carto 7. Falls Church, VA. American Society of Photogrammetry and American Congress on Surveying and Mapping, 142-151.

Elassal, and Caruso, V., 1983. "Digital Elevation Models." USGS Digital Cartographic Data Standards, Geological Survey Circular 895-B.

Kelly R.E., McConnell, P.R.H., and Mildenberger, S.J., 1977, "The Gestalt Photomapping System." Photogrammetric Engineering and Remote Sensing, Vol 43, No. 11 , 1407-1417.

Olsen, R., 1979, "Analysis of digital terrain profile data." Western Mapping Center, U.S. Geological Survey. Photocopy.

U. S. Geological Survey, 1978, "Evaluation of Digital Elevation Model data." Research Project Report #WMC-21. Western Mapping Center, U. S. Geological Survey. Photocopy.

National Mapping Program
Technical Instructions

Part 2
Specifications

Standards for Digital Elevation Models

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FIGURES

2. SPECIFICATIONS

2.1 DEFINITIONS: ERRORS AND BLUNDERS

DEM data contain errors of three types: blunders, which should be removed prior to entry to the data base; systematic errors, occurring in a system-specific or a procedure-specific pattern; and accidental errors, which are of a purely random nature and are completely unpredictable. Although all three types may be reduced in magnitude by refinements in technique and precision, they never can be completely eliminated.

2.1.1 Blunders

For DEM data, a blunder is an error signature typically of major proportions exceeding the maximum error permitted for each DEM level (see section 2-3) and as such is easily identifiable. Moreover a blunder is an indication that the data collection process has deteriorated beyond the level of simple systematic or random errors. Every effort is made to eliminate identifiable blunders during the processing and quality control operations. However, despite design precautions, some blunders may still remain.

2.1.2 Systematic Errors

Systematic errors are those errors that are introduced by procedures or systems and are typically predictable but not easily correctable. These types of errors cause a bias or artifact in the final product, but are not large enough to be considered a blunder. For DEM data, typical systematic errors include: vertical datum shifts, either for the quadrangle as a whole or for individual local areas or profiles; fictitious features, such as phantom tops, ridges, benches, or striations; and improper interpretation of terrain surfaces due to the effects of trees, buildings, and shadows, that prevent a clear interpretation of the terrain surface. Unidentified and uncorrected systematic errors are included in and contaminate the accuracy statistics used to describe the final DEM product.

2.1.3 Random Errors

Random errors are those errors considered to be observational in nature, or a result of measuring precision. They are caused by both system and human limitations. Random errors generally conform to a normal error distribution.

2.1.4 Root-Mean-Square Error

The root-mean-square-error (RMSE) statistic is used to describe the accuracy of a DEM, encompassing both random and systematic errors.

Accuracy is computed by comparison of linear interpolated elevations in the DEM with corresponding known elevations. Test points should be well distributed, representative of the terrain, and have true elevations with accuracies well within the DEM accuracy criteria. Acceptable test points may include; spot elevations or points on contours from existing 7.5-minute maps with appropriate contour interval; aerotriangulated test points; or field control.

The RMSE is defined as:

$$RMSE = \sqrt{\frac{\Sigma(Z_i - Z_t)^2}{n}}$$

where Z_i = interpolated DEM elevation of a test point
Z_t = true elevation of a test point
n = number of test points

Since test point elevations, Z_t, contain errors, "true" is actually the "most probable value"

2.2 ACCURACY

2.2.1 Horizontal Accuracy

Horizontal accuracy of DEM data is dependent upon the units of resolution of the elevation matrix (i.e. 30 meters). Therefore, within a standard DEM, most features are assumed to be generalized to the nearest 30 meters in the horizontal dimension. Also, an implicit link exists between horizontal and vertical accuracy wherein the predominate measure of accuracy is represented almost totally by tests of the vertical dimension.

Also implicit in all considerations of horizontal accuracy is the relationship of horizontal accuracy to procedures and systems leading up to the collection of raw data. These systems are subject to procedural and calibration standards affecting horizontal accuracies commensurate with standard mapping operations. For cartographic-source DEM data, horizontal accuracy is highly dependent on original materials. Existing quadrangles are assumed to conform to National Map Accuracy Standards (NMAS), where 90 percent of well-defined map features are to be within 0.02 inches. Further, USGS map digitizing accuracy is within 0.005 inches of the map position after correction for geometric distortions. For photogrammetric-source DEM data, digitized stereomodels are oriented to horizontal control points, obtained by either field control or aerotriangulation methods, providing a horizontal reference datum well within NMAS standards.

2.2.2 Vertical Accuracy

Vertical accuracy of DEM data is dependent on both the spatial resolution and the limitations imposed by data sources, procedures, and systems. The 30-meter spatial resolution results in data intervals which span terrain discontinuities, such as benches, tops, and drainage, resulting in smoothing. As with horizontal accuracy, collection systems are subject to procedural and calibration standards affecting vertical accuracies commensurate with standard mapping operations. For cartographic-source DEM data, vertical accuracy is highly dependent on original materials. Existing quadrangles are assumed to conform to National Map Accuracy Standards (NMAS), where 90 percent of elevations tested are to be within one-half contour interval. Further, USGS map digitizing accuracy is within 0.005 inches of the map position after correction for geometric distortions. For photogrammetric-source DEM data, digitized stereomodels are oriented to vertical control points, obtained by either field control or aerotriangulation methods, providing a vertical reference datum well within NMAS standards.

Vertical accuracy specifications for DEM data are dependent on the production methodology, e.g. cartographic source, photogrammetric source, degree of editing. Classification levels are specified in section 2.3.

2.3 CLASSIFICATION LEVELS

The following is a description of the general data characteristics used to classify DEMs into one of three levels of quality. There are varying methods of data collection and degrees of editing available for DEM data. Classification levels are indicated in the DEM Record A.

2.3.1 Level 1

Level 1 DEM's are considered to be elevation data sets in a standardized format. The intent for DEM data at this level is that no point contain any errors over 50 meters in elevation or that an array of points not encompass more than 49 contiguous elevations (an effective 7 by 7 array) in error by more than 21 meters. Systematic errors within stated accuracy standards are tolerated at this level. DEM data acquired photogrammetrically, using manual profiling or the Gestalt Photo Mapper, are restricted to the level 1 category. For NHAP-source data, an elevation RMSE of 7 meters is considered to be a reasonable desired accuracy standard, attainable under a variety of terrain and instrument conditions. A RMSE of 15 meters in elevation is the maximum permitted.

Data failing to meet these standards through established testing procedures (see Part 4, Quality Control) are not entered into the NDCDB and are either returned for further editing or rejected outright. The DEM Record C contains the RMSE accuracy statistic recording either the computed or estimated accuracy statistic acquired during quality control processes. The computed statistic shall be the result of a formal test of absolute accuracy. In the absence of a formal test of absolute accuracy, the appropriate field in Record C, that is, data element number 6, is coded as estimated.

2.3.2 Level 2

Level 2 DEM's are elevation data sets that have been processed or smoothed for consistency and edited to remove identifiable systematic errors. DEM data acquired by contour digitizing, either photogrammetrically or from existing maps, are entered into the level-2 category after review on a DEM Editing System. A RMSE of one half contour interval, not to exceed 7 meters in elevation, is the maximum permitted. There are no errors greater than two contour intervals in magnitude. The DEM Record C contains tested accuracy statistics as stated above.

2.3.3 Level 3

Level 3 DEM's are data sets that have been vertically integrated to insure positional and hypsographic consistency with planimetric data categories such as hydrography and transportation. DEM data in the level-3 category are derived from digital line graph (DLG) data using selected elements from both hypsography (contours, spot elevations) and hydrography (lakes, shorelines, drainage). If necessary, ridgelines and hypsographic effects of major transportation features are also included in the derivation. A RMSE of one-third of the contour interval, not to exceed 7 meters in elevation, is the maximum permitted. There ar no errors greater than one contour interval in magnitude. The DEM Record C contains tested accuracy statistics as stated above.

2.4 FORMAT

The logical format for DEM data sets is listed in Appendices 2-A, 2-B, and 2-C for logical record types A, B, and C.

The following physical structure is required for all DEM data files for entry into the NDCDB:

- o Data recorded in IBM fixed-block format on unlabeled 9-track magnetic tape at 1,600 bpi density.

- o Logical record size of 1,024 bytes. No more than one logical record type (A, B, or C) recorded in any 1,024-byte record. However, more than one 1,024 byte record is usually required to store a single record type B. The logical record is padded with blanks if necessary to fill to the end of the logical record. Bytes 1021-1024 of each logical record are padded with blanks.

- o Physical record size of 4,096 bytes; that is, 4 logical records per physical record.

- o Data written as ANSI standard ASCII characters.

The mapping center of DEM origin is named in record A, bytes 141-144. Valid codes are EMC, GPM2 (specific to EMC), MCMC, RMMC, WMC and FS (for Forest Service data). Codes indicating other sources of DEM's (other government agencies, private contractors) will be defined when required.

APPENDIX 2-A.--Digital Elevation Model Data Elements
Logical Record Type A

Data Element	Contents	Type (FORTRAN Notation)	Physical Record Format: ASCII Format	Physical Record Format: BINARY Format (Bytes)	Comment
1	File name, origin code	ALPHA	A144	144	Bytes 141-144 contain Mapping Center origin code. Valid codes are EMC, WMC, MCMC, RMMC, FS, GPM2.
2	DEM Level Code	INTEGER*2	I6	2	Code 1=DEM-1 2=DEM-2 3=DEM-3
3	Code defining elevation pattern (regular or random)	INTEGER*2	I6	2	Code 1=regular 2=random Normally set to Code 1.
4	Code defining ground planimetric reference system	INTEGER*2	I6	2	Code 0,=Geographic 1,=UTM 2,=State Plane For codes 3-20, see Appendix 2-F. Normally set to code 0 representing the geographic (latitude/longitude) system for 1:250,000-scale DEM's. Normally set to code 1 representing the UTM standard coordinate system for 7.5-minute DEM's.
5	Code defining zone in ground planimetric reference system	INTEGER*2	I6	2	Codes for State plane and UTM coordinate zones are given in Appendixes 2-D and 2-E for 7.5-minute DEM's. Code is set to zero for 1:250,000-scale DEM's

APPENDIX 2-A.--Digital Elevation Model Data Elements
Logical Record Type A--continued

Data Element	Contents	Type (FORTRAN Notation)	Physical Record Format: ASCII Format	Physical Record Format: BINARY Format (Bytes)	Comment
6	Map projection parameters (see Appendix 2-F)	REAL*8	15D24.15	15 x 8 = 120	Definition of parameters for UTM projection is given in Appendix 2-F. All 15 fields of this element are set to zero and should be ignored when geographic, UTM, or State plane coordinates are coded in data element 4.
7	Code defining unit of measure for ground planimetric coordinates throughout the file	INTEGER*2	I6	2	Code 0,=Radians 1,=feet 2,=meters 3,=arc-seconds Normally set to Code 2 for 7.5-minute DEM's. Normally set to Code 3 for 1:250,000-scale DEM's.
8	Code defining unit of measure for elevation coordinates throughout the file	INTEGER*2	I6	2	Code 1,=feet 2,=meters Normally code 2 for meters for 7.5-minute DEM's and 1:250,000-scale DEM's.
9	Number (n) of sides in the polygon which defines the coverage of the DEM file	INTEGER*2	I6	2	Usually n=4.
10	A 4, 2 array containing the ground coordinates of the four corners for the DEM	REAL*8	4(2D24.15)	64	The coordinates of the quadrangle corners are ordered in a clockwise direction beginning with the southwest corner. The array is stored row-wise as pairs of eastings and northings.

APPENDIX 2-A.--Digital Elevation Model Data Elements
Logical Record Type A--continued

Data Element	Contents	Type (FORTRAN Notation)	Physical Record Format: ASCII Format	Physical Record Format: BINARY Format (Bytes)	Comment
11	A two-element array containing minimum and maximum elevations for the DEM	REAL*8	2D24.15	16	The values are in the unit of measure given by data element 8 in this record.
12	Counterclockwise angle (in radians) from the primary axis of ground planimetric reference to the primary axis of the DEM local reference system	REAL*8	D24.15	8	See figure 2-1. Normally set to zero to align with the coordinate system specified in element 4.
13	Accuracy code for elevations	INTEGER*2	I6	2	Code 0,=unknown accuracy 1,=accuracy information is given in logical record type C.
14	A three-element array containing DEM spatial resolution (x,y,z). Units of measure for these resolution elements are consistent with those indicated by data elements 7 and 8 in this record	REAL*4	3E12.6	12	These elements are usually set to 30, 30, 1 for 7.5-minute DEM's and 3, 3, 1 for 1:250,000-scale DEM's. These units should not be confused with accuracy of the data.
15	A two-element array containing the number of rows and columns (m, n) of profiles in the DEM	INTEGER*2	2I6	4	See figure 2-1. Normally the row value m is set to 1. Thus, the n value normally describes the number of columns in the DEM file.

APPENDIX 2-B.--Digital Elevation Model Data Elements
Logical Record Type B

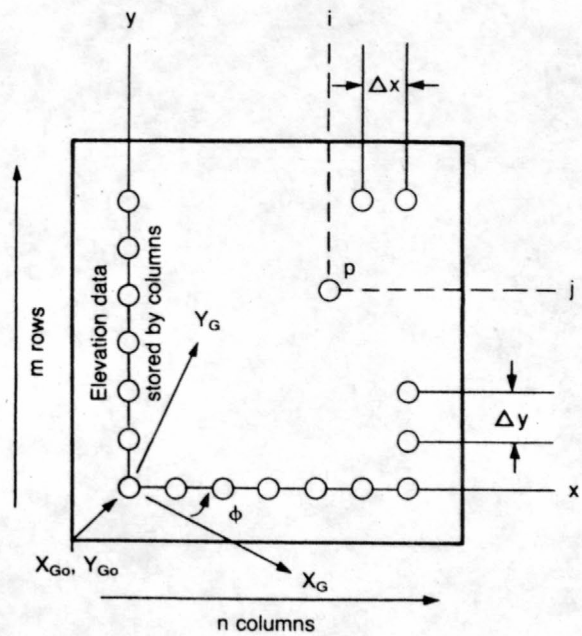
Data Element	Contents	Type (FORTRAN Notation)	Physical Record Format: ASCII Format	Physical Record Format: BINARY Format (Bytes)	Comment
1	A two-element array containing the row and column identification number of the DEM profile contained in this record	INTEGER*2	2I6	4	See figure 2-1. The identification numbers range from 1 to m and 1 to n. Rows are normally set to 1 and should be disregarded. The column identification is the profile sequence number.
2	A two-element array containing the number of rows and columns (m,n) of elevations in the DEM profile	INTEGER*2	2I6	4	See figure 2-1. This first element in the field corresponds to the number of nodes in this profile. The second element in this field is normally set to 1, specifying 1 column per B record.
3	A two-element array containing the ground planimetric coordinates (X_{go}, Y_{go}) of the first elevation in the profile	REAL*8	2D24.15	16	See figure 2-1.
4	Elevation of local datum for the profile.	REAL*8	D24.15	8	The values are in the units of measure given by data element 8 in logical record type A.

APPENDIX 2-B.--Digital Elevation Model Data Elements
Logical Record Type B--continued

Data Element	Contents	Type (FORTRAN Notation)	Physical Record Format: ASCII Format	Physical Record Format: BINARY Format (Bytes)	Comment
5	A two-element array of minimum and maximum elevations for the profile	REAL*8	2D24.15	16	The values are in the unit of measure given by data element 8 in logical record type A.
6	An array of m x n elevations for the profile. Elevations are expressed in units of resolution elements	INTEGER*2	mn(I6)	2mn	See data element 14 in Appendix 2-A. A value in this array would be multiplied by the spatial resolution value and added to the elevation of the local elevation datum for the profile (data element 4 in this record) to obtain the elevation for the point. The planimetric ground coordinates of the point X_{gp}, Y_{gp}, are computed according to the formulas in figure 2-1.

APPENDIX 2-C.--Digital Elevation Model Data Elements
Logical Record Type C

Data Element	Contents	Type (FORTRAN Notation)	Physical Record Format: ASCII Format	Physical Record Format: BINARY Format (Bytes)	Comment
1	Switch indicating availability of statistics in data element 2	INTEGER*2	I6	2	Code 1,=available 0,=unavailable
2	RMSE of file's datum relative to absolute datum (x,y,z)	INTEGER*2	3I6	6	In same units as indicated by elements 7 and 8 of logical record type A.
3	Sample size on which statistics in data element 2 are based	INTEGER*3	I6	2	If = 0 then accuracy will be assumed to be estimated rather than computed.
4	Switch indicating availability of statistics in data element 5	INTEGER*2	I6	2	Code 1,= available 0,=unavailable
5	RMSE of DEM data relative to file's datum (x,y,z)	INTEGER*2	3I6	6	In same units as indicated by elements 7 and 8 of logical record type A.
6	Sample size on which statistics in data element 5 are based are based	INTEGER*2	I6	2	If 0, then accuracy will be assumed to be estimated rather than computed.



(1)

$$x_p = (i-1)\,\Delta x$$

$$y_p = (j-1)\,\Delta y$$

(2)

$$X_{Gp} = X_{Go} + x_p\cos\phi - y_p\sin\phi$$

$$Y_{Gp} = Y_{Go} + x_p\sin\phi + y_p\cos\phi$$

Figure 2-1--Geometry and nomenclature of the DEM file

APPENDIX 2-D.--Codes for State Plane Coordinate Zones

Alabama, East (AL)	0101
Alabama, West	0102
Alaska (AK)	5001
	thru 5010
Arizona, Central	0203
Arizona, East (AZ)	0201
Arizona, West	0202
Arkansas, North (AR)	0301
Arkansas, South	0302
California (CA)	0401
	thru 0407
Colorado, Central	0502
Colorado, North (CO)	0501
Colorado, South	0503
Connecticut (CT)	0600
Delaware (DE)	0700
District of Columbia (DC)	1900
Florida, East	0901
Florida, North (FL)	0903
Florida, West	0902
Georgia, East (GA)	1001
Georgia, West	1002
Hawaii (HI)	5101
	thru 5105
Idaho, Central	1102
Idaho, East (ID)	1101
Idaho, West	1103
Illinois, East (IL)	1201
Illinois, West	1202
Indiana, East (IN)	1301
Indiana, West	1303
Iowa, North (IA)	1401
Iowa, South	1402
Kansas, North (KS)	1501
Kansas, South	1502
Kentucky, North (KY)	1601
Kentucy, South	1602
Louisiana, North (LA)	1701
Louisiana, Off Shore	1703
Louisiana, South	1702
Maine, East (ME)	1801
Maine, West	1802
Maryland (MD)	1900
Massachusetts, Island	2002
Massachusetts, Mainland (MA)	2001
Michigan, Central	2102
Michigan, Central (Lambert)	2112
Michigan, East (MI)	2101
Michigan, North (Lambert)	2111
Michigan, South (Lambert)	2113
Michigan, West	2103
Minnesota, Central	2202
Minnesota, North (MN)	2201
Minnesota, South	2203
Mississippi, East (MS)	2301
Mississippi, West	2302
Missouri, Central	2402
Missouri, East (MO)	2401
Missouri, West	2403
Montana, Central	2502
Montana, North (MT)	2501
Montana, South	2503
Nebraska, North (NE)	2601
Nebraska, South	2602
Nevada, Central	2702
Nevada, East (NV)	2701
Nevada, West	2703
New Hampshire (NH)	2800
New Jersey (NH)	2900
New Mexico, Central	3002
New Mexico, East (NM)	3001
New Mexico, West	3003
New York, Central	3102
New York, East (NY)	3101
New York, Long Island	3104
New York, West	3103
North Carolina (NC)	3200
North Dakota, North (ND)	3301
North Dakota, South	3302
Ohio, North (OH)	3401
Ohio, South	3402
Oklahoma, North (OK)	3501
Oklahoma, South	3502
Oregon, North (OR)	3601
Oregon, South	3602
Pennsylvania, North (PA)	3701
Pennsylvania, South	3702
Rhode Island (RI)	3800
South Carolina, North(SC)	3901
South Carolina, South	3902
South Dakota, North (SD)	4001
South Dakota, South	4002
Tennessee (TN)	4100
Texas, Central	4203
Texas, North (TX)	4201
Texas, North Central	4202
Texas, South	4205
Texas, South Central	4204

APPENDIX 2-D.--Codes for State Plane Coordinate Zones--continued

Utah, Central	4302
Utah, North (UT)	4301
Utah, South	4303
Vermont (VT)	4400
Virginia, North (VA)	4501
Virginia, South	4502
Washington, North (WA)	4601
Washington, South	4602
West Virginia, North (WV)	4701
West Virginia, South	4702
Wisconsin, Central	4802
Wisconsin, North (WI)	4702
Wisconsin, South	4803
Wyoming, Zone I, East (WY)	4901
Wyoming, Zone II, East Central	4902
Wyoming, Zone III, West Central	4903
Puerto Rico (RQ)	5301
Virgin Islands, St. Croix	5202
Virgin Islands, St. John, (VQ) St. Thomas	5201
American Samoa (AQ)	5300
Guam (GQ)	5400

APPENDIX 2-E.--Universal Transverse Mercator Zone Locations and Central Meridians

Zone	C.M.	Range	Zone	C.M.	Range
01	177W	180W-174W	31	003E	000E-006E
02	171W	174W-168W	32	009E	006E-012E
03	165W	168W-162W	33	015E	012E-018E
04	159W	162W-156W	34	021E	018E-024E
05	153W	156W-150W	35	027E	024E-030E
06	147W	150W-144W	36	033E	030E-036E
07	141W	144W-138W	37	039E	036E-042E
08	135W	138W-132W	38	045E	042E-048E
09	129W	132W-126W	39	051E	048E-054E
10	123W	126W-120W	40	057E	054E-060E
11	117W	120W-114W	41	063E	060E-066E
12	111W	114W-108W	42	069E	066E-072E
13	105W	108W-102W	43	075E	072E-078E
14	099W	102W-096W	44	081E	078E-084E
15	093W	096W-090W	45	087E	084E-090E
16	087W	090W-084W	46	093E	090E-096E
17	081W	084W-078W	47	099E	096E-102E
18	075W	078W-072W	48	105E	102E-108E
19	069W	072W-066W	49	111E	108E-114E
20	063W	066W-060W	50	117E	114E-120E
21	057W	060W-054W	51	123E	120E-126E
22	051W	054W-048W	52	129E	126E-132E
23	045W	048W-042W	53	135E	132E-138E
24	039W	042W-036W	54	138E	138E-144E
25	033W	036W-030W	55	147E	144E-150E
26	027W	030W-024W	56	153E	150E-162E
27	021W	024W-018W	57	159E	156E-162E
28	015W	018W-012W	58	165E	162E-168E
29	009W	012W-006W	59	171E	168E-174E
30	003W	006W-000E	60	177E	174E-180W

APPENDIX 2-F.--Parameters Required for Definition of Map Projections

Parameter	(00)* Geographic	(01)** Universal Transverse Mercator (UTM)	(02) State Plane	(03) Albers Conical Equal Area	(04) Lambert Conformal
1	***	Longitude of any point within the zone	***	Semi-major axis of ellipsoid. If this field is left blank (=0), the value for Clarke's 1866 spheroid in meters will be assumed.	
2	***	Latitude of any point within the UTM zone	***	Eccentricity squared of ellipsoid (e^2). If field is zero, this will indicate a sphere. If the field is 1, this field will be interpreted as containing the semi-minor axis of the ellipsoid.	
3	***	***	***	Latitude of 1st Standard Parallel	
4	***	***	***	Latitude of 2d Standard Parallel	
5	***	***	***	Longitude of Central Meridian	
6	***	***	***	Latitude of projection's origin	
7	***	***	***	False easting in the same units of measure as the semi-major axis of ellipsoid	
8	***	***	***	False northing in the same units of measure as the semi-major axis of ellipsoid	
9-15 (not used on this page)					

* Projection code number.
** For the Northern Hemisphere, supplying UTM zone will result in ignoring any given projection parameters.
*** Parameter is not applicable to projection.
Note: All angles (latitudes, longitudes, or azimuth) are required in degrees, minutes, and arc-seconds in the packed real number format +DDDOMMOSS.SSSSS.

APPENDIX 2-F.--Parameters Required for Definition of Map Projections--continued

Parameter	(05) Mercator	(06) Polar Stereographic	(07) Polyconic	(08) Equidistant Conic Type A	(08) Equidistant Conic Type B
1	Semi-major axis of ellipsoid. If this field is left blank (=0), the value for Clarke's 1866 spheroid in meters will be assumed.				
2	Eccentricity squared of ellipsoid (e). If this is left blank (=0), this will indicate a sphere. If the field is >1, this field will be interpreted as containing the semi-minor axis of the ellipsoid.				
3	***	***	***	Latitude of Standard Parallel	Latitude of 1st Standard Parallel
4	***	***	***	***	Latitude of 2d Standard Parallel
5	Longitude of Central Meridian	Longitude directed straight down below pole of map	. . . . . . Longitude of Central Meridian		
6	***	Latitude of true scale	. . . . . . Latitude of projection's origin		
7	. . . . . False easting in the same units of measure as the semi-major axis of ellipsoid				
8	. . . . . False northing in the same units of measure as the semi-major axis of ellipsoid				
9	***	***	***	Zero	Any non-zero number
10-15 (not used on this page)					

APPENDIX 2-F.--Parameters Required for Definition of Map Projections--continued

Parameter	(09) Transverse Mercator	(10) Stereographic	(11) Lambert Azimuthal Equal-Area	(12) Azimuthal Equidistant	(13) Gnomonic	(14) Orthographic
1	Same as Projections 03 thru 08	. . . . Radius of the sphere of reference . . . . If this field is left blank, the value 6370997.0 meters will be assumed				
2	Same as Projections 03 thru 08	***	***	***	***	***
3	Scale factor at Central Meridian	***	***	***	***	***
4	***	***	***	***	***	***
5	Longitude of Central Meridian	. . . . Longitude of center of projection				
6	Latitude of origin	. . . . Latitude of center of projection				
7	False easting in the same units of measure as the semi-major axis or radius of the sphere					
8	False northing in the same units of measure as the semi-major axis or radius of the sphere					
9-15 (not used on this page)						

APPENDIX 2-F.--Parameters Required for Definition of Map Projections--continued

Parameter	(15) General Vertical Near-Side Perspective	(16) Sinusoidal	(17) Equirectangular (Plate Caree)	(18) Miller Cylindrical	(19) Van Der Grinten I
1	. . . . Radius of the sphere of reference . . . . If this field is left blank, the value 6370997.0 meters will be assumed.				
2	***	***	***	***	***
3	Height of perspective point above sphere	***	***	***	***
4	***	***	***	***	***
5	Longitude of center of projection	. . . . Longitude of Central Meridian			
6	Latitude of center of projection	***	***	***	***
7	. . . . False easting in the same units of measure as radius of the sphere				
8	. . . . False northing in the same units of measure as radius of the sphere				
9-15 (not used on this page)					

APPENDIX 2-F.--Parameters Required for Definition of Map Projection--continued

Parameter	(20) Oblique Mercator (Definition Format A)	(20) Oblique Mercator (Definition Format B)
1	Same as for projections 03 thru 09	
2	Same as for projections 03 thru 09	
3	Scale factor at the center of projection	
4	***	Angle of azimuth east of north for central line of projection
5	***	Longitude of point along central line of projection at which angle of azimuth is measured
6	Latitude of origin of projection	
7	Same as for projections 03 thru 19	
8	Same as for projections 03 thru 19	
9	Longitude of first point defining central geodetic line of projection	***
10	Latitude of first point defining central geodetic line of projection	***
11	Longitude of second point defining central geodetic line of projection	***
12	Latitude of second point defining central geodetic line of projection	***
13	Zero	Any non-zero number
14 and 15 (not used for this projection)		

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3. COLLECTION OF ELEVATION DATA

The collection equipment and procedures used to generate raw DEM data vary widely with respect to capability to produce a uniform DEM data set. The observed differences in data quality and operational efficiency between equipment and procedures dictate that maximum DEM level classifications be identified for data dependent upon the source of the data sets. (See classification levels, Section 2.3)

Procedures used to generate DEM data are not specified in this standard but are determined by the mapping centers and described in procedure manuals.

3.1 DIGITAL LINE GRAPH SOURCE

This process involves the use of hardware such as raster scanners, manual digitizers, and automated line followers. These processes produce a digital line graph (DLG) from which the DEM is derived. Specifically, the hypsography and hydrography categories of DLG data are required as input to DEM processing, as shown in figure 3-1. Initial processing involves selection of specific line elements with requisite attribute codes. From the hypsography DLG, line data used include contours and spot elevations in three-dimensional coordinates. From the hydrography DLG, lake and shoreline data are used for water body flattening for a level 2 DEM. To produce a level 3 DEM, drainage data are extracted from the hydrography file and elevations are computed from contours. The various coordinate arrays are input to contour-to-grid software to interpolate gridded elevations for the DEM. A subsequent processing step involves trimming the grid along the quadrangle perimeter and formatting the data into a DEM file structure. The DEM is finally processed by the DEM Viewing and Editing System to validate and test the accuracy prior to entry to the National Digital Cartographic Data Base (NDCDB).

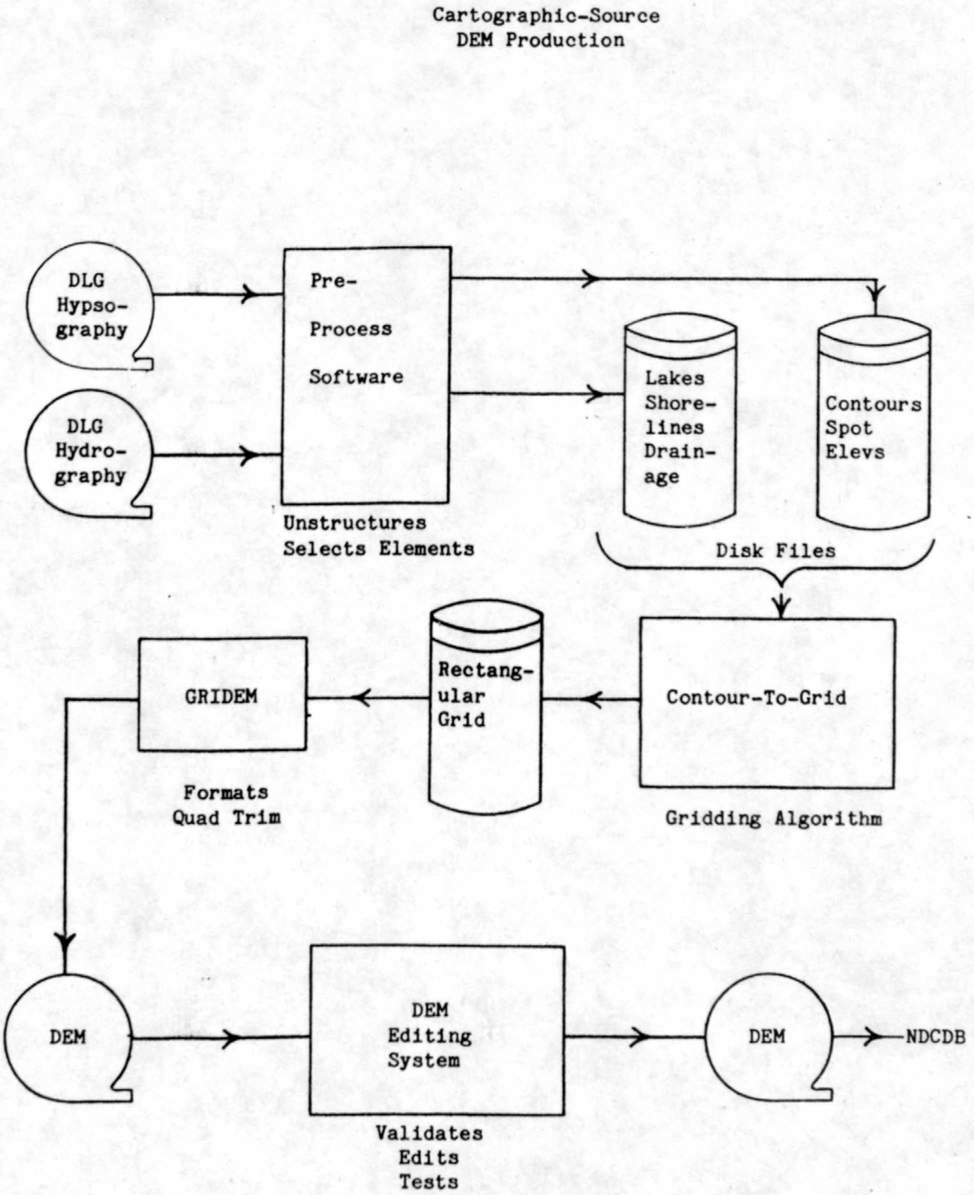

Figure 3-1

Production processes used to derive a DEM from DLG data.

3.2 PHOTOGRAMMETRIC DIGITIZING BY AUTOMATIC IMAGE CORRELATION

The Gestalt PhotoMapper (GPM) is used to collect DEM data using automatic image correlation. National High-Altitude Photography (NHAP) film positives are marked with the required control information and mounted on the stages of the GPM. The parameters concerning registration are entered, and an adjustment solution is calculated for the first stereomodel, which covers one-half the quadrangle. The GPM then automatically correlates imagery for a small section (patch) of the stereomodel at a time. When interactive operation is required, the operator insures that the image correlation solution for the patch is correct and commands the system to step to the next patch. The GPM records elevations of the terrain in the patch at a fixed interval. The data files for both halves of the quad are recorded on magnetic tape and are subjected to quality control checks. Both models are processed through the computer program RESAMPLE. This program merges the two models, resamples and grids the data to a 30-meter interval, partitions the merged model along the calculated quadrangle boundary, and subjects the resultant model to quality control checks. Relative accuracy is determined by the consistency between patches and through model joins to each other. The data files are subjected to water-body editing using digitized shorelines of specified water bodies. The resultant DEM file is then output to magnetic tape and transferred to the USGS DEM Editing System for correction and verification. For editing the DEM can be viewed in 3 modes: as either a shaded-relief, a stereomodel, or a color-banded elevation display for visual detection of anomalies in the data set. Minor errors are corrected and the resultant file is released for cataloging and inclusion in the NDCDB as level 1 DEM.

3.3 PHOTOGRAMMETRIC DIGITIZING OF TERRAIN PROFILES

Photogrammetric stereoplotters equipped with three-axis digitizing systems are used to collect elevation data by terrain profiling. Current equipment that has provision for automatic drive in the profile direction includes the Wild A-7, A-8, B-8, and the Zeiss C-8 stereoplotters. As with the GPM, NHAP is used with a predetermined control solution. A profile interval and scanning velocity are selected based on terrain slope and desired accuracy. Point intervals along profiles are typically 1/2 to 1/4 of the profile interval. Point elevations are automatically digitized during profiling. The profiling process requires the operator to visually control the floating mark along the terrain surface. The raw data are processed through a computer program that transforms coordinates and elevations to the ground system and reformats the output to a DEM file structure. Software program GRIDEM panels the two models together, resamples to a 30-meter grid, trims profiles at the quadrangle perimeter, and generates accuracy statistics. A verification plot is produced for use in a quality control check. Digitized water body boundaries are used for water-body editing. The DEM is then submitted for editing on the USGS DEM Editing System and subsequent entry into the NDCDB as a level 1 DEM.

3.4 PHOTOGRAMMETRIC DIGITIZING OF CONTOURS

DEM data are also derived from the process of stereocompilation. The stereoplotter is fitted with a three-axis digitizer, which captures cartographic data digitally as the operator follows a feature in the stereomodel. The features are tagged with their identifying attributes as they are digitized. The digitized contours from all models covering a quad are processed for DEM generation. Grid values are assigned by an interpolation algorithm. After the grid is formed, the data are output to tape and processed through the USGS DEM Editing System for correction, verification, and determination of need for water-body editing as described above. When edited and accuracy tested, the file is released for inclusion in the NDCDB as a level 2 DEM.

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Part 4
Quality Control

Standards for Digital Elevation Models

Department of the Interior
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4. QUALITY CONTROL

Quality control is an integral part of the production process and includes project planning and the use of proper hardware, software, and procedures. It is the responsibility of each mapping center to employ techniques and procedures necessary to comply with all standards specified in this document. Only techniques and procedures approved by the Branch of Technical Management are to be used for testing, editing, manipulating, or filtering of DEM data. The following tests, inspections, and corrective actions are mandatory to ensure the accuracy and format of the DEM.

4.1 ACCURACY VERIFICATION

4.1.1 Statistical Testing

A representative sampling of test points is used to verify the accuracy of a DEM. Test points are located on contour lines, bench marks, or spot elevations. A minimum number of 20 test points per DEM is required. Specific standards regarding statistical accuracy and related testing criteria are described in Part 2, Specifications.

4.1.2 Water Bodies (level 1 & 2 DEM)

Water bodies contained in DEM data are edited when they conform to the following criteria:

- o Type
  - Ponds, lakes, reservoirs, and double-line drainage.
- o Size
  - Ponds, lakes and reservoirs that exceed 300 meters (about 1/2 inch at 1:24,000 scale) along one major axis.
  - Double-line drainage exceeding 150 meters (about 1/4 inch at 1:24,000 scale) in width. The drainage limits will be represented by closed polygons bounded by shorelines and contour crossings (or closing lines).

To establish the water body elevation of each of the individual polygons of a double-line drain, the contour crossing (or closing line) representing the lowest elevation of each polygon will be assigned as the water body elevation of that polygon.

The correct horizontal and vertical position or elevation are determined from published products or other office sources by procedures established by the mapping centers. The mapping centers edit water-body data using the map or orthophoto containing the most current water-body information. Horizontal position and shape are as important as the elevation.

4.1.3 Hydrography (level 3 DEM only)

For level 3 DEM, the grid is constrained by all hydrographic features contained within a DLG hydrography category, including drainage, lakes, swamps, and shorelines. Elevations of hydrographic features are determined through interpolation of contours using a registered DLG hypsography file.

DEM surfaces constrained to drains are treated as a special case of hypsographic faulting where the DEM surface is simply creased along the track line of the drain. Additionally, all 30-meter grid cells are tilted consistent with the direction of stream flow, along the track line of the drain. There are no unsupported breaks or discontinuities in the rate of slope of the drain.

4.1.4 Slopes

The intent of DEM production processes is to produce DEM data sets that are accurate representations of slope as well as elevation. Slope data are more critical to certain scientific applications than elevation. For this reason the DEM should be a reasonable estimate of a uniformly sloping earth surface, i.e. smooth within the grid and continuous from node to node except at natural break points such as streams, cliffs, and craters. Higher levels of DEM data derived from contours generally represent slope more accurately than level 1 DEM data.

4.2 LOGICAL AND PHYSICAL FORMAT VERIFICATION

The computer program, DEM Verify, serves as the standard software used to verify the logical and physical format as part of the data base entry procedure. Validation by this software applies to all DEM software systems of the USGS, other government agencies or contractors wherein data is intended for submission to the NDCDB. In all cases where the integrity of the logical or physical DEM structure is in question, DEM Verify will be regarded as the standard for format verification.

4.3 VISUAL VERIFICATION

Additional testing will be performed utilizing the USGS-developed DEM Editing System to aid in the identification of blunders such as irregularly gridded data, mistagging of tops and depressions, and spikes. These blunders are generally identified by visually displaying the DEM. The system options include color banding of elevation gradients, stereoscopic viewing using anaglyphic filters, and shaded-relief enhancement. An elevation matrix is analyzed in suspect areas and corrected as required.

Editing of maximum/minimum values applies to all DEM levels. Verification includes:

1. The maximum and minimum elevations contained in the DEM are identified and compared to the maximum/minimum values represented by contours or spot elevations on the best available map product of the area.

2. Maximum or minimum value identified in 1 above that fails to agree within stated error tolerances requires an examination of the data and map to determine a reason for the discrepancy. Editing of the data to bring the value into agreement may be required.

3. All elevations below sea level are verified according to the best available map product of the area and if unsupported, adjusted to the surrounding terrain.

4.4 EDITING

If it is judged economically feasible, the mapping centers will edit the DEM data set or reprocess the raw data. These edited or reprocessed data will be submitted for quality review and entry to the NDCDB. Failure of the DEM to meet the accuracy requirements or to pass the visual and software tests will be cause for rejection of the DEM.