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U.S. GEOLOGICAL SURVEY STANDARD FOR DIGITAL ORTHOPHOTOS

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U.S. GEOLOGICAL SURVEY STANDARD FOR DIGITAL ORTHOPHOTOS

Paper submitted by the United States of America

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ABSTRACT

The U.S. Geological Survey has added the new category of digital orthophotos to the National Digital Cartographic Data Base. This differentially rectified digital image product enables users to take advantage of the properties of current photoimagery as a source of geographic information. The product and standard were implemented in July 1992. The digital orthophotos are quadrangle based and cast on the Universal Transverse Mercator projection and extend beyond the primary datum theoretical 3.75-minute or 7.5-minute quadrangle neat line approximately 300 meters to form a rectangle. The overedge may be used for mosaicking with adjacent digital orthophotos. To provide maximum information content and utility to the user, metadata (header) records exist at the beginning of the digital orthophoto file. Header information includes the photographic source type, date, instrumentation used to create the digital orthophoto, and information relating to the DEM that was used in the rectification process. The North American Datum of 1983 (NAD 83) is considered the primary datum. Additional header information is included on transformation constants from the 1927 and 1983 North American Datums to the orthophoto internal file coordinates to enable the user to register overlays on either datum. The quadrangle corners in both datums are also imprinted on the image. Flexibility has been built into the digital orthophoto format for future enhancements, such as the provision to include the corresponding digital elevation model elevations used to rectify the orthophoto. The digital orthophoto conforms to National Map Accuracy Standards and provides valuable mapping data that can be used as a tool for timely revision of standard map products, for land use and land cover studies, and as a digital layer in a geographic information system.

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INTRODUCTION

The U.S. Geological Survey has been designated as a lead Federal agency for the collection and distribution of digital cartographic data. The standard for digital orthophotos pertains to the collection, processing, and quality control of digital orthophoto data for entry into the National Digital Cartographic Data Base.

In conjunction with its modernization program, the U.S. Geological Survey is developing a digital revision capability using digital orthophotos. The standard is intended to serve as a framework for developing this orthophoto capability. The requirements and technologies involved in producing digital orthophotos will remain dynamic for some time. The standard outlines many of the key dependencies and, in some cases, alternatives.

PROCESS DESCRIPTION

Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. A digital image is created by scanning an aerial photograph (film diapositive) using a precision image scanner. The digital photographic image is then digitally rectified to an orthographic projection by processing each image pixel through photogrammetric space resection equations. This process requires, as input, ground control points acquired from ground surveys or developed in aerotriangulation, the camera calibration and orientation parameters, and a digital elevation model (DEM). The rectified digital image is then archived on suitable digital storage media with informational header records inserted as the first four records of the digital image file. The image may also be written to film by a digital film writer.

APPLICATIONS

Digital orthophotos can serve the same purpose as hard copy orthophotos, from interim maps to field references for earth science investigations and analyses. The digital orthophoto is useful as a layer of a GIS system and as a tool for revision of digital line graphs and topographic maps. Image processing algorithms can be applied to the digital orthophoto to allow image classification, 3D-modeling, and other spatial and radiometric applications.

SOURCES

The production procedures and instrumentation used for the collection of digital orthophotos vary depending on what systems are available. At the present time, National Aerial Photography Program (NAPP) or NAPP-like photographs are the primary source used for the production of digital orthophotos by the USGS. NAPP photographs are quarter-quadrangle centered (3.75 minutes of longitude and latitude in geographic extent) and are exposed at a flying height of 20,000 feet above mean terrain with a 152.4 millimeter focal-length camera (photography scale = 1:40,000). Quadrangle (7.5-minute) digital orthophotos are produced either by mosaicking 3.75-minute digital orthophotos or from National High Altitude Photography (NHAP). Color-infrared photographs may be used as a source for digital orthophotos; however, the digital image file is a black-and-white (B&W) digital orthophoto. Other aerial photographic or digital sources may be used in the future.

PRODUCTION AND STORAGE

Digital orthophotos create large amounts of data that must be stored and distributed. The radiometric resolution of the image data pixels is 8 bits, which provides gray scale values of 0 to 255. The source image data ground pixel resolution varies depending on flying height, focal length of the camera, and scanning resolution. To extract the maximum information content from a 240-millimeter-square NAPP aerial photograph, a scanning aperture of 15 micrometers would be needed and would produce a raw data set of approximately 256 megabytes. A scanning resolution of 25 micrometers yields approximately 92 megabytes of raw data and equates to a ground resolution of 1 meter using 1:40,000-scale NAPP photographs. A quadrangle-based digital orthophoto generated and cropped from a 240-millimeter-square source scanned at 25 micrometers with the requisite overedge produces a rectified file of about 55 megabytes.

DIGITAL ORTHOPHOTO STRUCTURE AND FORMAT

The archive and distribution format of the digital orthophoto file contains four ASCII header records, followed by a series of 8-bit binary image data records. The digital orthophoto is cast on the Universal Transverse Mercator (UTM) projection on NAD 83. Digital orthophotos are archived and distributed so that when displayed on a computer graphics terminal, projection grid north is at the top.

For standard 3.75-minute digital orthophotos, the ground resolution is 1 meter; the resolution for the 7.5-minute digital orthophotos is 2 meters. Other ground pixel resolutions may be produced to support other image requirements.

The geographic extent of the digital orthophoto is equivalent to an orthophoto quarter-quadrangle or quadrangle (3.75 or 7.5 minutes), plus overedge coverage (approximately 300 meters) to encompass the four primary and secondary horizontal datum corner points. The resulting digital orthophoto is a rectangle, whose size may vary in relation to adjoining digital orthophotos due to geographic longitude convergence. Figure 1 shows the relationship between the digitized image, ground control points, source DEM, source orthophoto, and 3.75- or 7.5-minute quadrangle corners. Figure 1 also illustrates the size difference between the scanned photograph and the digital orthophoto.

HEADER - ARCHIVAL AND DISTRIBUTION FORMAT

The orthophoto image file has four header records. Each header record is composed of 400 bytes and is blank padded, as necessary, to equal the record length of the image data records. The digital orthophoto header format adheres to that specified in the Standards for Digital Orthophotos. Flexibility has been built into the digital orthophoto format to provide orderly transition for future enhancements. The four header records contain a wide range of descriptive information about the image data, including: file identification; the coordinate systems and datums upon which the digital orthophoto is cast; and lineage information relating to the source DEM, source photography, and ground control. Table 1 shows the complete structure of the four header records including the element number; name of data field; start, end, and number of bytes; FORTRAN format statement; and a short description of the element. The header is composed of the following records and elements.

Record 1 - First 400-byte record

Record 1 identifies the area of geographic coverage of the image, including the quadrangle name and 3.75-minute quadrant (assuming a digital orthophoto quarter quandrangle rather than a digital orthophoto quadrangle) within the 7.5-minute quadrangle. Separate Federal Information Processing Standard (FIPS) state/county fields are provided for up to four states and up to five counties. Other information in record 1 includes the producing organization for the data; the types and order of band storage; the types of elevation storage (DEMs are not included at the present time); specification of horizontal and vertical datums; and specification of the parameters of the UTM coordinate system. This record also contains the UTM ground coordinates of quadrangle corners in the primary horizontal datum.

Record 2 - Second 400-byte record

Record 2 contains transformation parameters and coordinates to allow conversion from the internal line and sample coordinate

system to the primary datum coordinate system. This record also contains the ground coordinates of quadrangle corners in the secondary horizontal datum.

Record 3 - Third 400-byte record

Record 3 contains transformation parameters and coordinates to allow conversion from the internal line and sample coordinate system to the secondary horizontal datum coordinate system. This record also contains line and sample (x-y) coordinates of the four theoretical quadrangle neat line corners in the primary and secondary horizontal datum and projection, as well as the horizontal coordinates in the primary and secondary horizontal datums of the first pixel (1,1) of the image file.

Record 4 - Fourth 400-byte record

Record 4 contains information related to the source DEM and lineage information related to the digital orthophoto acquisition systems, including the camera, scanner, processing software, and related resolutions of those systems. Since DEM's are not stored within the digital orthophoto file, DEM related fields are set to zero.

CONCLUSION

The information incorporated into the header of each digital orthophoto will enhance the product's usefulness to the user community. The digital orthophoto can be used as a data layer in a GIS system, and the inclusion of transformation constants allows for the registration of other data sets. The digital orthophoto can be used as a base on which to register digitized maps for revision and (or) update. Flying height, camera focal length, and scanning resolution allow for computing scale changes for output of the digital orthophoto to various hard-copy devices. Inclusion of elevation data allows for slope, drainage, aspect, and any other elevation-related studies to be performed. Additionally, elevation data may be used to generate isometric and perspective views of the orthophoto. Over edge imagery provides the possibility of mosaicking adjacent images. A ground resolution of 1 to 2 meters provides sufficient resolution for many soil, land use and land cover, and vegetative classifications and other analyses. Inquires on the Standard for Digital Orthophotos or the digital orthophoto program should be directed to Chief, Office of Technical Management, U.S. Geological Survey, 510 National Center, Reston, Virginia 22092.

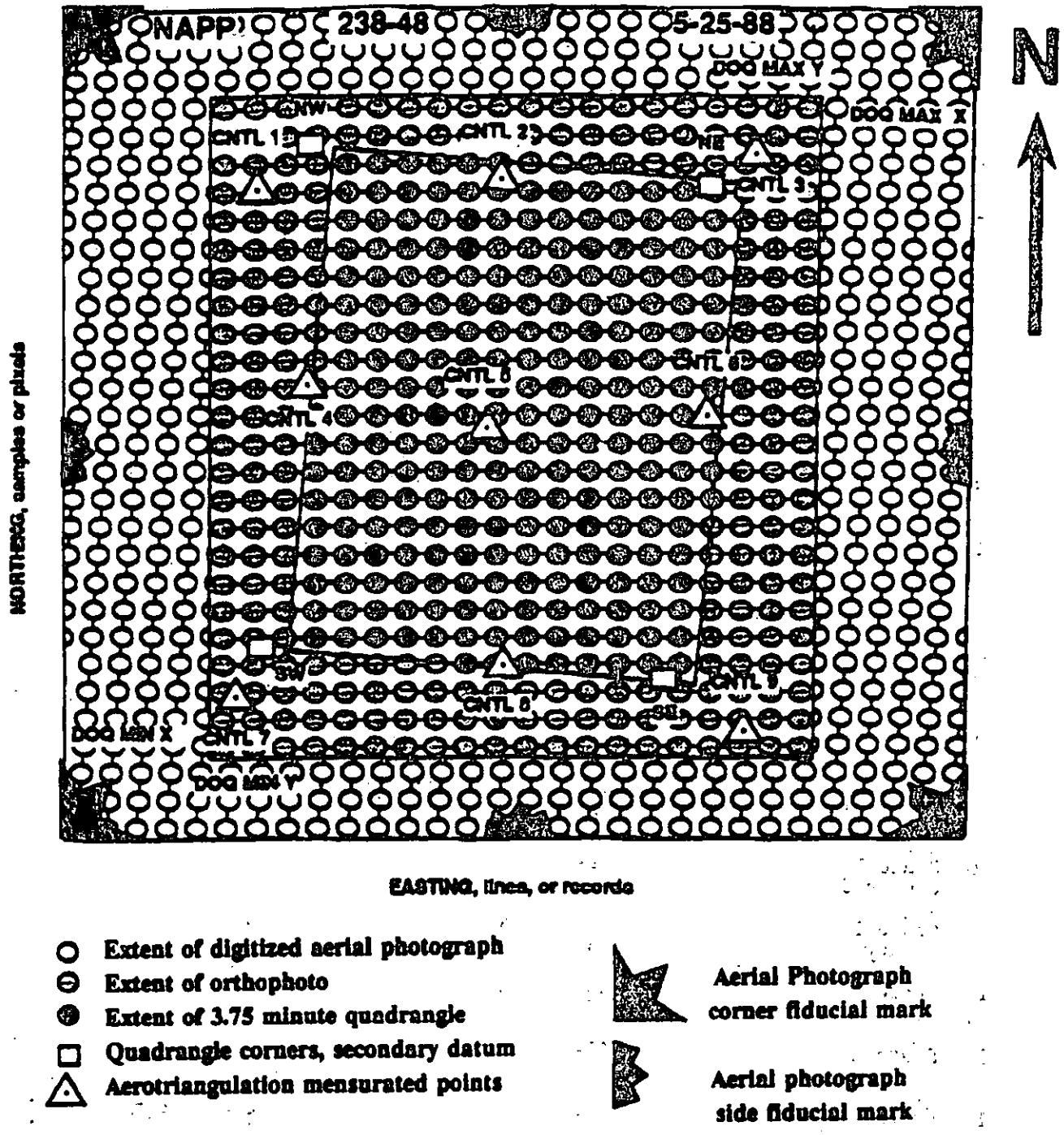

Figure 1. Digital orthophoto data structure.

Table 1. Digital Orthophoto Header Records

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 1		
1	Quadrangle name	38	1-38	A38	Authorized quadrangle name
2	Quadrant	2	39-40	A2	Quadrangle quadrant (SW, NW, NE, SE).
3	Nation	4	41-44	2A2	FIPS nation code. Valid codes are US, CA, MX (bytes 43, 44 blank if only one nation)
4	State 1	2	45-46	A2	FIPS PUB 6-4 first state in file.
5	State 2	2	47-48	A2	second state
6	State 3	2	49-50	A2	third state
7	State 4	2	51-52	A2	fourth state
8	State 1, County 1	3	53-55	A3	FIPS PUB 6-4 first county in first state.
9	State 1, County 2	3	56-58	A3	second county
10	State 1, County 3	3	59-61	A3	third county
11	State 1, County 4	3	62-64	A3	fourth county
12	State 1, County 5	3	65-67	A3	fifth county
13	State 2, County 1	3	68-70	A3	FIPS PUB 6-4 first county in second state.
14	State 2, County 2	3	71-73	A3	second county
15	State 2, County 3	3	74-76	A3	third county

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 1-Cont'd		
16	State 2, County 4	3	77-79	A3	fourth county
17	State 2, County 5	3	80-82	A3	fifth county
18	State 3, County 1	3	83-85	A3	FIPS PUB 6-4 first county in third state.
19	State 3, County 2	3	86-88	A3	second county
20	State 3, County 3	3	89-91	A3	third county
21	State 3, County 4	3	92-94	A3	fourth county
22	State 3, County 5	3	95-97	A3	fifth county
23	State 4, County 1	3	98-100	A3	FIPS PUB 6-4 first county in fourth state.
24	State 4, County 2	3	101-103	A3	second county
25	State 4, County 3	3	104-106	A3	third county
26	State 4, County 4	3	107-109	A3	fourth county
27	State 4, County 5	3	110-112	A3	fifth county
28	Reserved	2	113-114		Reserved for future use.
29	Filler	23	115-137	A23	Alpha filler for additional descriptive text.
30	Producer code	4	138-141	A4	Mapping center origin code EMC,MCMC,WMC,RMMC,FS,BLM,SCS (contractors use code of oversight mapping center)

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 1-Cont'd		
31	Data ordering	3	142-144	I3	1=samples n-s, lines w-e 2=samples w-e, lines n-s
32	No. of lines and samples	12	145-156	2I6	Number of lines & samples in single band
33	Band types, order, number of bands present, and storage sequence	3	157-159	I3	Code 1=1 band black & white (B&W) 2=1 band red 3=1 band green 4=1 band blue 5=3 band color (RGB) 6=3 band RGB + 1 band B&W 7=1 band B&W + elevation data 8=3 band RGB + elevation data 9=3 band RGB & 1 band B&W + elevation data
34	Elevation storage	3	160-162	I3	Code 0=not stored 1=by profile 2=by pixel Elevations stored as 2-byte values
35	Band & elevation storage	3	163-165	I3	Code 0=separate file(s) 1=band sequential in one file 2=band interleaved by band in one file 3=band interleaved by band/record in one file 4=band interleaved by pixel/record in one file
36	Vertical datum	2	166-167	I2	Code 1=Local mean sea level 2=National Geodetic Vertical Datum 1929 3=North American Vertical Datum 1988 (Blank if DEM not stored record 1,element 34 = 0)

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 1-Cont'd		
37	Primary Horizontal Datum	2	168-169	I2	Code 1=North American Datum 1927 (NAD 27) 2=World Geodetic System 1972 3=World Geodetic System 1984 4=North American Datum 1983 (NAD 83) 5=Old Hawaii Datum 6=Puerto Rico Datum
38	Secondary Horizontal Datum	2	170-171	I2	Same as record 1, element 37
39	Angle of rotation	24	172-195	D24.15	Counterclockwise angle (in radians) from the primary axis of ground planimetric reference to the primary axis of the orthophoto local reference system. Normally set to 0.0
40	Ground X-Y reference system	3	196-198	I3	Code 0=Geographic 1=Universal Transverse Mercator (UTM) 2=State Plane Coordinate System (SPCS)
41	Code defining zones in ground planimetric reference system	6	199-204	I6	Projection zone code. Set to zero for geographic projection
42	Ground X-Y planimetric units	3	205-207	I3	Code 0=radians 1=feet 2=meters 3=arc seconds
43	SW ground coordinate	48	208-255	2D24.15	X-Y unit ground coordinates of the four quadrangle corners in the projection and primary datum of
44	NW ground coordinate	48	256-303	2D24.15	

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 1-Cont'd		
45	NE ground coordinate	48	304-351	2D24.15	record 1, elements 37 and 40-42
46	SE ground coordinate	48	352-399	2D24.15	See record 1, element 43
47	Reserved	1	400		Reserved for future use
48	Blank Fill		401 - M		M = byte count of image
			RECORD 2		
1	a, b, c, d, e, f, xc & yc constants to convert internal line & sample coordinates to and from projection and primary datum, record 1, elements 37 & 40-42	192	1-192	8 D24.15	Transform from internal (line & sample) coordinates to ground or from ground coordinates to internal coordinates: e = Xcentroid f = Ycentroid xc = line centroid yc = sample centroid X = a(line-xc) + b(sample-yc)+e Y = c(line-xc) + d(sample-yc)+f g = (b/a)+(a/b) or h = (d/c)+(c/d) line = ((X-e)/b-(Y-f)/a)/g + xc sample = ((Y-f)/c-(X-e)/d)/h + yc
2	SW ground coordinate	48	193-240	2D24.15	X-Y unit ground coordinates of the four quadrangle corners in the projection and secondary datum of record 1, elements 38 and 40-42
3	NW ground coordinate	48	241-288	2D24.15	
4	NE ground coordinate	48	289-336	2D24.15	
5	SE ground coordinate	48	337-384	2D24.15	See record 2, element 2
6	Reserved	16	385-400		Reserved for future use
7	Blank Fill		401 - M		M = byte count of image

Element no.	Element	No of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 3		
1	a, b, c, d, e, f, xc & yc constants to convert internal line & sample coordinates to and from projection & secondary datum of record 1, elements 38 & 40-42	192	1-192	8D24.15	Same as record 2, element 1
2	SW internal coordinate	12	193-204	2I6	x-y unit internal coordinates (line and sample) of the quadrangle corners in the primary datum of record 1, elements 37 & 40-42. Corners are imprinted in the image as 4 solid white crosses. (see section 2.2)
3	NW internal coordinate	12	205-216	2I6	
4	NE internal coordinate	12	217-228	2I6	
5	SE internal coordinate	12	229-240	2I6	
6	SW internal coordinate	12	241-252	2I6	x-y unit internal coordinates (line and sample) of the quadrangle corners in the secondary datum of record 1, elements 38 & 40-42. Corners are imprinted in the image as 4 dashed white crosses. (see section 2.2)
7	NW internal coordinate	12	253-264	2I6	
8	NE internal coordinate	12	265-276	2I6	
9	SE internal coordinate	12	277-288	2I6	
10	First pixel X-Y coordinates (Primary datum)	48	289-336	2D24.15	Primary datum ground X-Y value of internal coordinate first line first pixel (1,1)
11	First pixel X-Y coordinates (Secondary datum)	48	337-384	2D24.15	Secondary datum ground X-Y value of internal coordinate first line first pixel (1,1)
12	Reserved	16	385-400		Reserved for future use
13	Blank Fill		401 - M		M = byte count of image

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 4		
1	Elevation units	3	1-3	I3	Code 1=feet 2=meters
2	Minimum orthophoto elevation	10	4-13	F10.3	Values are in units of record 4, element 1. ***
3	Maximum orthophoto elevation	10	14-23	F10.3	Value in units of record 4, element 1. ***
4	X ground resolution	12	24-35	E12.6	Ground X-Y-Z resolution of DEM, in X-Y units of record 1, element 42 and
5	Y ground resolution	12	36-47	E12.6	Z in units of record 4, element 1. ***
6	Z ground resolution	12	48-59	E12.6	See record 4, element 4 ***
7	X pixel resolution	12	60-71	E12.6	Ground pixel resolution, X-Y in units of record 1, element 42 and Z in units
8	Y pixel resolution	12	72-83	E12.6	of record 4, element 1. Z set to 0.0 if record 1, element 27=0
9	Z pixel resolution	12	84-95	E12.6	See record 4, element 27
10	Largest primary contour interval	5	96-100	I5	Interval if source DEM derived from graphic, & two or more primary intervals, otherwise zero ***
11	Largest primary contour interval units	1	101	I1	Corresponds to the units of the map largest primary contour interval 1=feet, 2=meters ***
12	Smallest primary contour interval	5	102-106	I5	Set to zero if no primary contour interval or source not a graphic ***
13	Smallest primary contour interval units	1	107	I1	Corresponds to the units of the map smallest primary contour interval 1=feet, 2=meters ***

*** If record 1, element 34, elevation storage code = 0 (elevations not stored), then these fields, which are DEM specific, are default to zeroes.

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 4 -- continued		
14	Suspect and void areas in elevation data used to make orthophoto or missing image data	2	108-109	I2	Code 0=none 1=suspect 2=void 3=suspect & void Image imprinted with digital value of 0.
15	Horizontal DOQ accuracy	6	110-115	F6.1	RMSE of image control points for X-Y, expressed in units of record 1, element 41
16	Vertical DEM accuracy	6	116-121	F6.1	RMSE of primary DEM used to rectify image. Use largest RMSE if more than one primary DEM.
17	Number of DOQ horizontal test points	4	122-125	I4	Minimum of four, usually nine
18	Pixel processing algorithm	2	126-127	I2	Code 0=nearest neighbor 1=bilinear 2=cubic convolution
19	Production system	24	128-151	A24	Alphanumeric description of hardware & software used
20	Production date	10	152-161	I6,2I2	Four-digit year, two-digit month & day (bbYYYYMMDD)
21	Film type	24	162-185	A24	Manufacturer & ID of film type
22	Source photograph identification	24	186-209	24A1	Alphanumeric description of photograph, agency, roll number, exposure number, etc.
23	Mosaicked Image	3	210-212	I3	Code 0=not mosaicked n=number of chips composing image
24	Leaf off, flag	2	213-214	A2	Flag = "Lb" for leaf off, otherwise flag = "bb", (b=blank).

Element no.	Element	No. of bytes	Start and end bytes	FORTRAN format	Description
			RECORD 4 - continued		
25	Source photograph date	8	215-222	I4,2I2	Four digit year, two digit month & day (YYYYMMDD)
26	Camera focal length	8	223-230	F8.3	Calibrated camera focal length in millimeters
27	Source photograph flying height	10	231-240	I10	Nominal flying height of photograph in units of record 4, element 1
28	Scanner type	24	241-264	A24	Alphanumeric description stating manufacturer, model number, etc.
29	Scanning resolution	12	265-276	2F6.2	Aperture resolution in x and y directions in microns
30	Scanner sampling resolution	12	277-288	2F6.2	Sampling resolution in x and y directions in microns.
31	Radiometric resolution of image	3	289-291	I3	Code 1=8 bits 2=16 bits
32	Resampled Resolution	6	292-297	F6.2	Code 0.0=not resampled, else resampled resolution
33	Reserved	103	298-400		Reserved for future use
34	Blank Fill		401 - M		M = byte count of image
			RECORDS 5 - N		
5 - N	Data records	--	---	--	Image data are records 5 - N where N equals the number of lines of data. See appendix 2-C for examples of structure of valid types of image data.