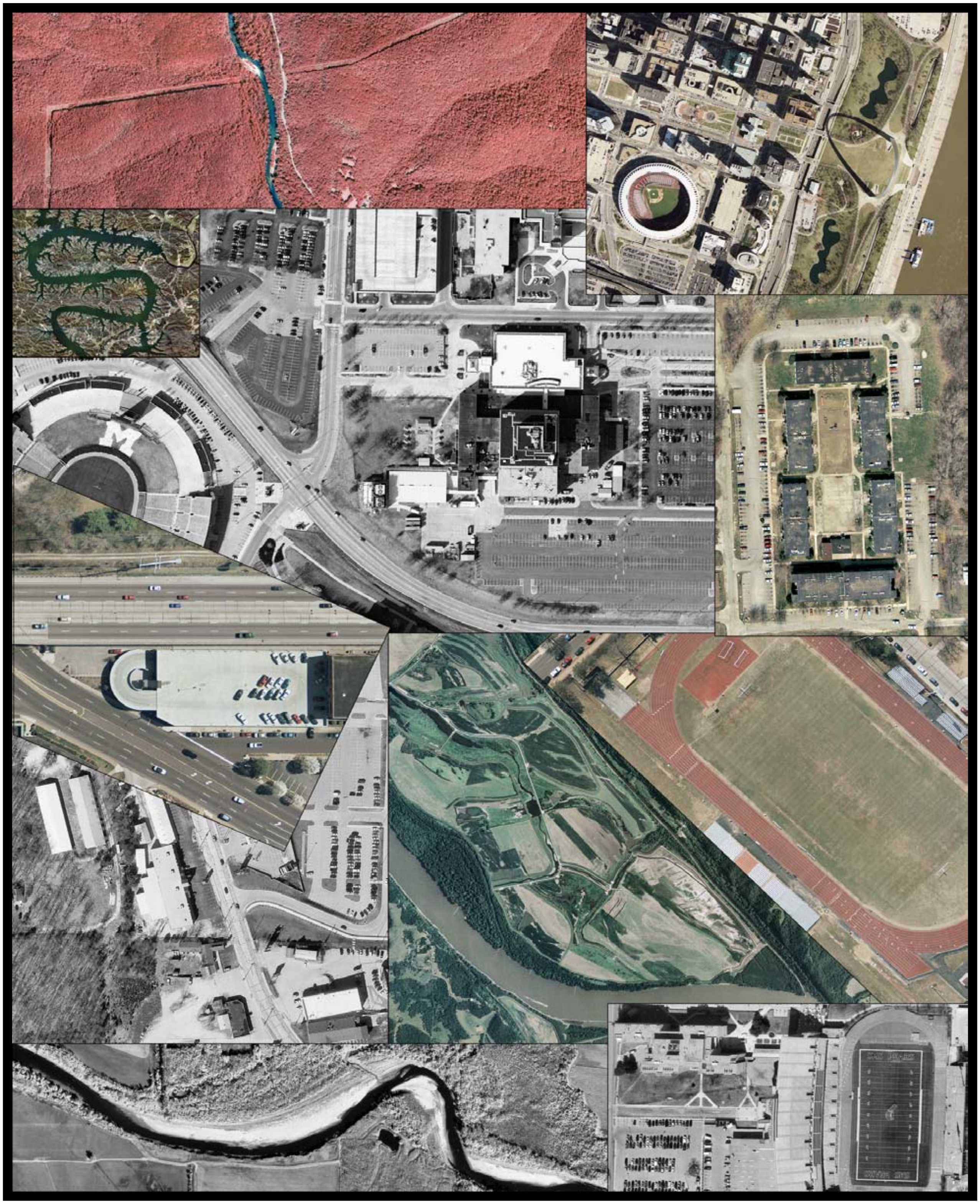
STATE OF MISSOURI
DIGITAL ORTHOPHOTOGRAPHY STANDARDS



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1. Introduction

This document contains the elements necessary for the creation of a standard for digital orthoimagery. It is the intent of this standard to set a common baseline that will ensure the widest utility of digital orthoimagery for the user and producer communities through enhanced data sharing and the reduction of redundant data production.

1.1. Objective

The objective of this standard is to define the orthoimagery theme of the digital geospatial data framework as envisioned by the Missouri GIS Advisory Committee. It is the intent of this standard to set a common baseline that will ensure the widest utility of digital orthoimagery for the user and producer communities through enhanced data sharing and the reduction of redundant data production. The framework will provide a base on which to collect, register, and integrate digital geospatial information accurately. Digital orthoimagery is a part of this basic set of data described as framework data.

This standard is intended to facilitate the interchange and use of digital orthoimagery data under the framework concept. Because of rapidly changing technologies in the geospatial sciences, this standard for digital orthoimagery covers a range of specification issues, many in general terms. This document stresses complete and accurate reporting of information relating to quality control and standards employed in testing orthoimagery data.

1.2. Scope

This standard describes processing, accuracy, reporting, and applications considerations for NSDI Framework digital orthoimagery, and may be applicable to other data sets, which employ the FGDC Framework concepts. This standard is classified as a Data Content Standard by the Federal Geographic Data Committee Standards Reference Model and Missouri GIS Advisory Committee. Data content standards provide semantic definitions of a set of objects, such as those described above.

1.3. Applicability

This standard applies to NSDI Framework digital orthoimagery produced, or disseminated by or for the Federal Government. According to Executive Order 12906, Coordinating Geographic Data Acquisition and Access: the National Spatial Data Infrastructure (Clinton, 1994, Sec. 4., Data Standards Activities), Federal agencies collecting or producing geospatial data, either directly or indirectly (i.e. through grants, partnerships, or contracts with other entities), shall ensure, prior to obligating funds for such activities, that data will be collected in a manner that meets all relevant standards adopted through the FGDC process.

1.4. Relationship to Existing Standards

Throughout this text there are numerous references to metadata and the FGDC's "Content Standard for Digital Raster Metadata Draft" (FGDC, 1994), Content Standard for Digital Orthoimagery, Content Standard for Framework Land Elevation Data." Whenever a comment about metadata appears, the location of the data element description in that standard, placed in parentheses ( ), will follow.

1.5. Standards Development Procedures

The draft State of Missouri Digital Orthophotography Standards have been developed by the Standards Subcommittee of the Missouri GIS Advisory Committee.

1.6. Maintenance

The Missouri GIS Advisory Committee (MGISAC) maintains the State of Missouri Digital Orthophotography Standards. Please address any questions concerning this standard to the chair of the MGISAC Standards Subcommittee.

2. Data Description

A digital orthoimage is a georeferenced image prepared from a perspective photograph or other remotely-sensed data in which displacement of objects due to sensor orientation and terrain relief have been removed. It has the geometric characteristics of a map and the image qualities of a photograph. Digital orthoimages are composed of an array of georeferenced pixels that encode ground reflectance as a discrete value. Digital orthoimagery comes from various sources and in a number of formats, spatial resolutions, and areas of coverage. Many geographic features, including some in other framework data themes, can be interpreted and compiled from an orthoimage. Accurately positioned, high resolution data are considered the most useful to support the compilation of framework features.

3. Digital Orthoimagery Structure

Framework digital orthoimagery shall consist of two-dimensional, rectangular arrays of pixels, which correspond to ground areas called ground resolution cells. The pixels shall be arranged in horizontal rows (lines) and vertical columns (samples). The order of the rows shall be from top to bottom; the order of columns shall be from left to right. The uppermost left-hand pixel shall be designated pixel (0,0). Each line of image pixels represents a physical record in the file with the total set of records constituting a single file of one or more bands. Images should be stored as an industry accepted format described in Appendix.

The file shall have equal record lengths, resulting in a rectangular or squared image. This may be accomplished by padding with overedge image or non-image pixels, with digital number (DN) equal to zero (black), to an edge defined by the extremes of the image. The bounding coordinates of the image must be documented in accordance with the FGDC "Content Standard for Digital Raster Metadata." For images that contain overedge imagery or are padded with non-image pixels, descriptions of both the specific area of interest and any overedge imagery must be documented by the metadata standard. For instance, some digital orthoimagery quadrangles include overedge imagery beyond the boundaries of the area of interest. Therefore, the producer is obliged to describe the image quadrangle in metadata.

Both the image area of interest proper, and the overedge, shall be documented in the metadata field: *(Spatial_Domain/Bounding_Coordinates and Data_Quality_Information/ Attribute_Accuracy/Completeness_Report)*.

3.1. Format

The State of Missouri Digital Orthophotography Standards recommends that the GeoTIFF format be used. GeoTIFF represents an effort by over 160 different remote sensing, GIS, cartographic, surveying, and related companies and organizations to establish a TIFF-based interchange format for georeferenced raster imagery. This specification closely follows the organization and structure of the TIFF specification document. (GeoTIFF Format Specification 1.0, Specification Version: 1.8.2, Last Modified: 28 December, 2000).

3.2. Image Radiometry

Relative radiance of ground resolution cells are described by digital numerical representations (DNs or brightness values) of reflected radiance amplitudes. The cell value is recorded as a series of binary digits or bits, with the number of bits per cell determining the radiometric resolution of the image. (I.e.. 8 bit has a range of 0 – 255 values)

4. Non-image data

Image files may contain non-image data in the form of header or trailer records that are embedded with the image data or contained in separate files. These records offer information used to identify, georeference, and impart other information about the data. They are generally in a different format than the image data. Producers of imagery shall document pertinent information about these records: i.e., their location, byte counts, etc., in the metadata.

5. Sources

Sources for the creation of digital orthoimagery can be collected from a variety of traditional and emerging remote sensing devices. The processing of the acquired data will vary depending on the remote sensing instrument and therefore can be accomplished in a number of ways.

All sources employed in the creation of digital orthoimagery shall be documented in the metadata field: *(Data_Quality_Information/Lineage/Source_Information).*

In general, the minimum components needed to create digital orthoimagery are:

Control –- A combination of surveyed points and airborne GPS based collection, aerotriangulation solution, and inertial measurement unit (IMU) data considerations.

Unrectified Raw Images -- Files either from scanned aerial film negatives or other remote sensing instruments.

Sensor Calibration Information – Details about the instrument(s) used.

Surface Model –- Elevation data that covers the same geographic area as the final image product.

The components listed above are used collectively to mathematically register individual image files to one another as well as their orientation with respect to the earth's surface at the time of acquisition. Then, radial and relief displacement are removed from the raw images through the actual orthorectification processing activity.

5.1. Control

The production of digital orthophotography requires the use of control data as represented by both horizontal (X and Y) and vertical (Z) values for physically paneled/targeted points and/or photo-identifiable points and GPS coordinates collected for every exposure during the overflight (airborne GPS).

The accuracy requirements and distribution of control points will be dictated by the intended resolution of the final orthoimagery products.

A description of the methods used to establish control shall be documented in the metadata field: *(Data_Quality_Information/Positional_Accuracy/Horizontal_Positional_Accuracy/Horizontal_Positional_Accuracy_Report).*

5.1.1. Airborne GPS

Airborne GPS (AbGPS) has successfully been used for controlling digital orthophotography since the early 1990s. As a quality control measure, ABGPS data should be collected for every exposure and combined with targeted/photo-identifiable control points in the aerotriangulation solution.

5.1.2.Inertial Measurement Unit Considerations

Inertial measurement units (IMUs) can be used as supplemental control information in creation of digital orthophotography; however, IMU data is not intended to replace other control methodologies as cited previously and not to be relied upon as an individualized control solution.

5.1.3.Aerotriangulation Solution

The aerotriangulation (AT) solution provides a densification of control point data to the control data collected in the field and in the aircraft (i.e. AbGPS). Specific AT requirements such as interior and exterior orientation procedures will not be outlined in this standard. The AT solution should follow industry accepted root mean square error (RMSE) tolerances to support creation of the specified digital orthoimage product as defined in a mutually agreed accuracy standard.

5.2. Raw Image Files

Raw image files may come from traditional remote sensing devices such as frame based mapping cameras using various film emulsions or from new and emerging sensors such as digital cameras, light detection and ranging (LiDAR) systems, or RADAR.

5.2.1.Seasonal and Time-of-Day Considerations

The season of the year and the time of day when images are acquired can be significant factors contributing to the utility of the imagery. Regardless of application (i.e. leaf-on vs. leaf-off), aerial photography should be captured when the sun angle is at least thirty degrees to the earth's surface.

In addition to sun angle, another important element for consideration is having cloud-free imagery. Cloud-free days will help yield higher contrasting image products; therefore, aerial photography missions should occur in as close to cloud-free conditions as possible.

The following table provides general guidelines as to when (from time of day and calendar perspectives) the sun's angle is greater than thirty degrees to Jefferson City, Missouri (38.5N, 92.2W) and an average of how many cloud-free days can be expected during a given month. There are only about forty days during the calendar year (December 3rd through January 11th) that the sun's angle does not reach greater than thirty degrees. In all practicality, a three hour block of time is considered a minimum acquisition window; therefore, the table only shows dates with windows of three hour periods.

Date	Time of Day	Average Cloud-free Days
January 31	10:38am – 1:39pm	4.5
February 15	9:59am –2:19pm	4.5
March 15	9:00am – 3:18pm	4.0
April 15	8:13am – 4:05pm	4.5
May 15	7:43am – 4:34pm	4.5
June 15	7:30am –4:47pm	4.0
July 15	7:34am – 4:43pm	3.5
August 15	7:56am –4:22pm	5.0
September 15	8:34am –3:43pm	7.5
October 15	9:28am – 2:50pm	9.5
November 13	10:39am –1:38pm	5.0
Note: The above times represent local times in Missouri at the specific calendar date. These windows of time should be understood as general and nature and specific timeframes should be verified with the service provider prior to the overflight.		

The date and the time of day that the images were acquired shall be documented in the metadata field.

5.2.2.Film Based Aerial Photography

Film based aerial photography is still a primary source used to produce digital orthoimagery. Film emulsion types for orthoimagery compliant with the standard are: black and white (panchromatic), color infrared (CIR), natural (true) color, and black and white infrared.

Metadata required includes the type of film, manufacturer or agency identification, and roll and exposure number: *(Lineage:Source_Information/Source_Citation).*

Scanned Images From Aerial Photography

The combination of the Instantaneous Field Of View (IFOV) of the scanner and the scale of the source imagery shall determine the pixel ground resolution, which can be attained for the digital orthoimagery (Pratt, 1978). Resampling to a pixel ground resolution greater (coarser) than that of the original scan is acceptable and, in many cases desirable, to create smaller file sizes. Excessive subsampling to attain a pixel ground resolution value less (finer) than that of the source imagery is not permitted. The table shown below outlines common scanning resolutions associated with various photo scales to achieve a certain ground pixel resolution end product.

Ortho Ground Pixel Resolution	Representative Fraction	Photo Scale	Scanning Resolution
0.25'	1:300	1"=400'	15 microns
0.5'	1:600	1"=800'	15 microns
1.0'	1:1200	1"=1600'	15 microns
2.0'	1:2400	1"=3333'	15 microns
1.0M	1:3600	1"=3333'	25 microns
2.0M	1:7200	1"=3333'	50 microns

Non-Film Based Aerial Photography

Non-film based aerial photography includes electro-optical imaging instruments which typically use two-dimensional detector arrays of charge-couple devices (CCDs). Each detector in the array is the equivalent of one pixel in the image. At the present, because of the relatively small size of the arrays, electro-optical instruments such as digital cameras are more suited for capturing large scale images with ground sample distances measuring in the sub-meters.

Appropriate information about the device, type, array size, pixel resolution, and flight height, will be cited in the image metadata. *(Data_Quality_Information/Lineage/Process_Step/Process_Description).*

5.3. Sensor Calibration Data

While camera or imaging instrument calibration parameters are required for production purposes, specifications for that data will not be covered by this standard; however, any remote sensing instrument used for the production of digital orthoimagery will require calibration data to generate a reasonable aerotriangulation solution. Currently, the USGS provides camera calibration services for film based frame cameras and is likely to be the lead government agency developing standards for non-film based sensors.

5.4. Surface Elevation Model Data

The creation of digital orthophotography requires the use of a surface model to correct displacement associated with terrain changes in the area covered by the corresponding image. Surface models shall consist of both mass points and breaklines where available with sufficient accuracy and density to ensure the final image product meets the agreed upon horizontal accuracy requirements for the intended scale.

The use of existing surface models for orthorectification should be explored for new digital orthophotography projects; however, given that a surface model represents the earth's surface at the time of creation, means that it must be checked to determine whether or not it will meet the product accuracy requirements without adjustment. For example, the National Elevation Dataset (NED) may be suitable for producing digital ortho quads (DOQs), the resolution and character of the NED will not support the accuracy requirements associated with a 0.5' ground pixel resolution digital orthophoto.

A detailed description of the source Elevation Model shall be documented in the metadata field: *(Lineage:Source_Information/Source_Citation)*

For more information on elevation data refer to the FGDC "Content Standards for Digital Gridded Land Elevation Data".

6. Areal Extent

This standard places no constraints on the geographic extent of orthoimagery. Areal extent of orthoimagery may be adjusted as appropriate for the type of sensor and sensor platform, height, requirements of the user, etc. However, it is recommended that producers of digital orthoimagery data utilize a widely used or familiar tiling scheme. Numerous established schemes exist for partitioning the Earth's surface. The USGS 7.5-minute topographic map series utilizes one such method. Schemes based upon subsets of the 7.5-minute topographic map could be used for large-scale image tiling schemes. Full tiles will be produced for geographic area of interest. Other examples include tiles based on the Public Land Survey System (PLSS) or other cadastral systems based on county boundaries, tax plats, etc.

The spatial domain of an image shall be documented in the metadata field: *(Identification_Information/Spatial_Domain)*.

7. USGS Tiling Methodology

A common method for tiling imagery data is essential for integrating framework data. A USGS standard tile-naming scheme based on the USGS Missouri Index to topographic and other Map Coverage is recommended. The USGS 7.5-minute standard quadrangle maps cover systematically subdivided areas of latitude and longitude. The National Digital Orthophoto Program has completed statewide coverage of Missouri with quarter-quadrangle orthophotos centered on one quarter of a USGS quadrangle covering 3.75 x 3.75 minutes. The 3.75-minute quarter-quadrangle cell name is based upon the 7.5-minute cell name followed by the appropriate directional quadrant, specified as NE, NW, SW, or SE that is the parameter for the keyword quadrant. A 7.5-minute quadrangle name may contain a directional quadrant as part of their proper quadrangle name (National Mapping Program Technical Instructions, Part 2 – Specifications, Standards for Digital Orthophotos. 12/96)

For example, the Jefferson City NW 7.5-minute quadrangle is divided into four 3.75-minute quarter-quadrangles. These quarter-quadrangles are named Jefferson City NW NW, Jefferson City NW NE, Jefferson City NW SW, and Jefferson City NW SE.

For orthophotos that cover less than 3.75 minutes of latitude and longitude, a detailed explanation of the convention used needs to be made available in an accompanying read me file.

8. Georeferencing

This standard specifies that image data be referenced to real world locations. Framework data should be referenced using the following standards for projection, coordinate system and datum. Local georeferencing should utilize a known standard such as the State Plane Coordinate System.

8.1. Projection and Coordinate System:

Framework will utilize Transverse Mercator projection and Universal Transverse Mercator (UTM) grid coordinates in meters, local zone 15 or 16. For statewide applications the recommendation would be to use Zone 15. This would require reprojection from Zone 16 to Zone 15. UTM Zone 15 is the standard UTM zone for the area from 90 to 96 degrees longitude, which does not include portions of southeastern Missouri. For most applications the error introduced by extending zone 15 to include southeastern Missouri does not warrant using two projections (zones 15 and 16).

The projection shall be documented in the metadata field: *(Spatial_Reference_Information/Horizontal_Coordinate_System_Definition/Grid_Coordinate_System/ Grid_Coordinate_System_Name).*

8.2. Datum:

This standard recommends that the North American Datum of 1983(NAD83) be used as the horizontal datum for digital orthoimagery. In recognition of significant application of other widely accepted datums throughout the digital geospatial community, other datums may be referenced.

In each instance the horizontal datum shall be documented in the metadata field: *(Spatial_Reference_Information/Horizontal_Coordinate_System_Definition/Geodetic_Model).*

8.3. Image Georegistration:

Georegistration of the image is also essential to complete georeferencing of the image. Georegistration will be described by a 4-tuple in the metadata, which will establish the position of the first pixel in the first row of the image [pixel (0,0)]. The metadata will reflect the row # = 0, column # = 0, and georeference values in X and Y for the documented datum and horizontal coordinate system. Under this standard, georegistration (spatial coordinates) refers to the center of the pixel. This establishes the georegistration at one point in the orthoimage. Since row and column offsets are both constant and known, (XY_pixel resolution), all other points can be georegistered. Additional 4-tuples may be provided for additional georegistration.

Georegistration of pixel (0,0) shall be documented in the metadata field: *(Spatial_Reference_Information/Horizontal_Coordinate_System_Definition/Planar_Coordinate_Information/Local_Planar_Georeference_Information).*

Note: Different software may read image formats and assume where georeferenced site is located.

9. Resolution

Two separate resolution measurements are important for image data: pixel ground resolution, which is sometimes referred to as horizontal ground resolution or ground sample distance, and radiometric resolution. For this standard, pixel ground resolution defines the area of the ground represented in each pixel in x and y components, while radiometric resolution defines the sensitivity of a detector to differences in wavelength as it records radiant flux reflected or emitted from the ground.

9.1. Pixel Ground Resolution

Images may be resampled to create coarser resolution images than the original raster data. Subsampling of images may be applied only within the limits defined by the Nyquist theorem (Pratt, 1978). The Nyquist frequency limits subsampling to a maximum two times (2X) to avoid undesirable aliasing.

The pixel ground resolution shall be documented in the metadata field: *(Spatial_Reference_Information/Horizontal_Coordinate_System_Definition/Planar/Planar_Coordinate_Information)*.

9.2. Radiometric Resolution

This standard recommends at a minimum that black and white image data be represented as 8-bit binary data, and color images be represented as 24-bit, 3 byte data. For 8-bit and 24-bit image data, digital numbers, or image brightness values shall be represented by 256 gray levels and represented by a number in a range of zero-255. A value of zero shall represent the color black and a value of 255, the color white. All intermediate values are shades of gray varying uniformly from black to white. Areas where the image is incomplete shall be represented with a numeric value of zero. Higher radiometric resolution may be warranted by application.

Radiometric resolution shall be documented in the metadata field: *(Spatial_Data_Organization_Information:Direct_Spatial_Reference_Method/Raster_Object_Information)*

10. Accuracy

Map scale and accuracy are closely related in maps made from aerial photography. Map features will appear larger on larger-scale maps and can potentially be located more accurately. Aerial cameras with 9-inch film format and 6- or 12-inch focal length lenses are so widespread in map production that photo scale, map scale, accuracy and image resolution have become locked together.

Digital photogrammetry introduces new relationships. There is a source scale associated with a digital pixel that is often referenced by the ground sample distance (GSD) or pixel size on the ground. Accuracy depends on camera calibration, position knowledge, pointing knowledge and ground control.

Users should determine the horizontal accuracy required for their specific application. Modern standards specify accuracy independent of scale or pixel size. Because accuracy terms quantify accuracy differently, they should be stated clearly to ensure that the imagery products are responsive to users' needs. Specific methods for determining accuracy are outlined in the National Accuracy Standards (NMAS) and National Standards for Spatial Data Accuracy (NSSDA) documents.

Useful Resolution Groups for Engineering & Planning
From: "Selection of Maps for Engineering & Planning",
Committee on Cartographic Surveying, Journal of the Surveying and Mapping Division,
Proceedings of the American Society of Civil Engineers, July, 1972. Table 1, p.112

	Scale			
	Type of Map	**Representative Fraction**	**Feet**	**Meters**
Design				
Critical	10 to 50	1:100 to 1:500	.2 to 5	.1 to 1
General	40 to 200	1:500 to 1:2000	.05 to 10	.1 to 2
Planning				
Micro	100 to 1000	1:1000 to 1:10000	1 to 20	.2 to 5
Local	400 to 2000	1:5000 to 1:25000	2 to 50	.5 to 10
Regional	1000 to 10000	1:10000 to 1:100000	5 to 100	1 to 20
National	10000 to 100000 (2 to 20 miles)	1:100000 to 1:1000000	10 to 1000	2 to 200

11. Data Quality

Quality of the final product of digital orthoimagery will be dependent on the quality of inputs as well as the processing techniques employed for production.

11.1. Quality of Inputs

The primary inputs of control, raw images and surface models will each impact the quality of the final product. A quality control and assurance process should be employed prior to acceptance of inputs.

11.1.1.Control

Control may be derived from a number of sources, including photo targets, photo-identifiable points, airborne GPS, IMUs and aerotriangulation. The sources and density of control desired will depend on the accuracy requirements of the project. However, this standard discourages sole reliance on the later three sources of control.

The distribution of control is important to achieving accurate referencing. Control should be spatially distributed, non-linear, and throughout each raw image, with emphasis toward the extremes of the image.

The interplay of control and the surface model will determine a measurable horizontal positional accuracy of features on the image. Terrain relief, platform position, and faulty elevation data are the sources of nonsystematic distortion, or random errors in the final product. These random errors can be detected by comparing identifiable points on an image to their known ground coordinates. Positional accuracy should be at least as good as the National Map Accuracy Standards for the nominal scale of the output.

National Map Accuracy Standards Horizontal Accuracy Examples Scale of 1" Represents NMAS*	
1:1200 = 100 ft	±3.33 ft
1:2400 = 200 ft	±6.67 ft
1:4800 = 400 ft	±13.33 ft
1:9600	±26.67 ft
1:10000	±27.78 ft
1:12000 = 1000 ft	±33.33 ft
1:24000 = 2000 ft	±40.00 ft
1:63360 = 5280 ft	±105.60 ft
1:100000	±166.67 ft
*National Map Accuracy Standards (NMAS) define the requirements for meeting horizontal accuracy as 90% of all measurable points must be within 1/30th of an inch for maps at scale of 1:20000 of larger, and 1/50th of an inch for maps at scales smaller than 1:20000.	

11.1.2.Raw Images

Regardless of their source, the raw images used to produce a digital orthoimage will affect its overall quality. Many factors dictate image clarity and quality, including camera quality and condition, radiometric ground calibration of camera, film processing techniques, atmospheric conditions at the time of acquisition, sun angle, spectral range and resolution of the sensor, and aspects that obscure the target information (in most cases, the ground). This standard assumes that all appropriate techniques of acquisition and handling will be employed, and only offers specific guidelines for minimizing obstruction of the ground.

Clouds, Smoke, Haze, and Other Aerosols

Any cloud or cloud shadow that obscures image features may render the image unusable. However, for some areas of an image (i.e. over large bodies of water) cloud cover obstruction may be deemed acceptable to some users. Therefore, some users may find images containing varying percentages of cloud cover or cloud shadow to be acceptable.

Other atmospheric aerosols such as haze or smoke may cause similar issues as clouds. When developing contractual standards for image collection one should be aware of natural or man-made conditions, such as large-area, seasonal grass fires, that might obscure the ground during overflights.

In general terms, "no ground obstruction" is the desired condition of orthoimagery. However, such stringent requirements will increase the cost and possibly lengthen the flight schedule for collection of imagery.

The percentage of cloud cover, haze or smoke obstruction shall be recorded in the metadata field: *(Data_Quality_Information/Cloud_Cover)*.

Flooding

Water covering areas where it normally does not, similar to cloud cover, can make images less valuable. Of course, for flood assessment or wetland inventory, times of high water might actually be the desired state for images. But generally, images should be collected during "normal" water levels, with in-bank rivers and less-than-saturated soils, for optimal interpretation. One should keep in mind that water condition can vary greatly from one location to another, and depending on the size of the project area will need to be locally assessed.

11.1.3. Surface Model

As discussed previously, the surface elevation model paired with the control determines the geometric accuracy of digital orthoimages. The elevation model accuracy requirements depend on the scale of the imagery and their intended use. The minimum accuracy recommended for DOQ production is the Level 2 accuracy as defined in the USGS Standard for Digital Elevation Models.

Images may be determined to be unacceptable when artifacts appear in areas where critical features are evident, or if artifacts are of such an extent to render the image unusable.

11.2. Output Quality

11.2.1. Radiometry Issues

Image brightness values may deviate from the brightness values of the original imagery, due to image value interpolation during the scanning, rectification, and post-processing procedures. The scanners should be calibrated to a standardized gray field with measures of mean and variance reported.

Data producers are cautioned to minimize the amount of radiometric correction applied to an image. It is common practice to perform some radiometric enhancements and corrections (i.e., contrast stretching, analog dodging, noise filtering, destriping, edge matching) to images prior to release of the data. Data producers shall use processing techniques which minimize data loss from the time the information was captured until its release to the users. Any image restoration or enhancement processes applied to an image shall be documented in the metadata field: *(Data_Quality_Information/Lineage/Process_Step/Process_Description)*.

Radiometric accuracy can be verified by visual comparison of the digital orthoimage with the original unrectified image to determine if the digital orthoimagery has the same or better image quality as the original unrectified input image(s).

Radiometric accuracy verification process and results shall be documented in the metadata field: *(Data_Quality_Information:Attribute_Accuracy/Attribute_Accuracy_Report)*.

Resolution

The flying height, camera specifications (and thus the photo scale) and scanning resolution determine digital orthoimagery resolution. See the table in section 5.2.2.1 for scanning resolution and the resulting ground resolution. Imagery should be collected consistent with the desired ground resolution without reliance on subsampling.

Resampling

Nearest neighbor, bilinear interpolation, and cubic convolution resampling algorithms are common methods used to transform image values to fit map geolocation values. Nearest neighbor resampling is not recommended for the large-scale framework because of the disjointed appearance in the output due to spatial offsets as great as one-half pixel. Images transformed using bilinear interpolation are generally acceptable. A precise resampling method such as cubic convolution is recommended.

Most importantly, the resampling process utilized in the production of the image must be documented in the metadata field: *(Data_Quality_Information /Lineage/Process_Step/Process_Description)*.

11.2.2.Image Mosaicking

Single orthoimages are commonly created through the mosaicking of multiple images. Temporal and seasonal differences between source images should be minimized to avoid incongruence across join lines. When a mosaic of two or more digital orthoimage tiles is made, the tile judged by visual inspection to have the best contrast shall be used as the reference image. The brightness values of the other image tile shall be adjusted to match that of the reference tile. The join lines between the overlapping tiles shall be chosen so as to minimize tonal variations. Localized adjustment of the brightness values shall be performed to minimize tonal differences between join areas.

Identification of the multiple sources as well as the extent of each tile of a mosaicked image shall be documented in the metadata field: *(Data_Quality_Information/Lineage/Source_Information/Source_Citation)*.

A scheme must be selected for mosaicking. For example, quarter quadrangles are mosaicked into quadrangles, and quadrangles into counties. Thought should be given to overedge among mosaic tiles.

11.2.3.Histogram Matching

Histogram matching is a process of making the range and distribution of spectral values similar among image tiles. Histogram matching makes viewing of multiple images side-by-side more visually satisfactory because they have similar tonal appearance.

Histogram matching has positive and negative effects on the final product. Matching suppresses variation among images and reduces the ability to differentiate features. It also results in the digital image differing from the source imagery. However, it allows the user to use bordering tiles with a more seamless appearance without mosaicking.

Histogram matching should be done with minimum change to the original appearance of the image. Careful selection of the histogram to match, capturing the full range of reflection values of the data set, will result in a more satisfactory product. One might consider two products, one histogram matched during a mosaicking process, and unmatched images more true to the original data.

12. Data Completeness

Visual verification shall be performed for image completeness, to ensure that, whenever possible, no gaps exist in the image area.

Areas of omission, in incomplete images, shall be documented in the metadata field: *(Data_Quality_Information/Completeness_Report)*.

12.1. Cloud Cover

Any cloud cover or cloud shadows which obscure image features may render the image unusable. However, for some areas of an image (i.e. over broad bodies of water) cloud cover obstruction may be deemed acceptable to some users. Therefore, some users may find images containing varying percentages of cloud cover or cloud shadow to be acceptable.

The percentage of cloud cover obstruction shall be recorded in the in the metadata field: *(Data_Quality_Information/Cloud_Cover)*.

13. Image Mosaicking

Single orthoimages are commonly created through the mosaicking of multiple images. Temporal and seasonal differences between source images should be minimized to avoid incongruence across join lines. When a mosaic of two or more digital orthoimage chips is made, the chip judged by visual inspection to have the best contrast shall be used as the reference image. The brightness values of the other chips shall be adjusted to match that of the reference chip. The join lines between the overlapping chips shall be chosen so as to minimize tonal variations. Localized adjustment of the brightness values shall be performed to minimize tonal differences between join areas.

Identification of the multiple sources as well as the extent of each chip of a mosaicked image shall be documented in the metadata field: *(Data_Quality_Information/Lineage/Source_Information/Source_Citation)*.

14. Metadata

The FGDC emphasizes the importance of good metadata, in order to provide quality information about data which will allow users to match data to their needs. This standard describes a general set of specifications, and as such, places most of the burden on the user to assess quality and applicability of data. Appropriate metadata facilitates this process. Certainly, for the user, data with documentation is more useful than data that has none. The more high quality metadata there is for a product, the more it can support the user's determination of its reliability, quality, and accuracy. Metadata is intended to be of value to the producer as well as to the user.

The FGDC's "Content Standards for Digital Geospatial Metadata" will be the source for all issues relating to terminology and definitions relating to metadata.

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Appendix – Definitions (Informative)

Aerotriangulation - The process of precisely orienting aerial or satellite imagery to the control system defined for a project

Bilinear interpolation - the mathematical computation for an unknown value based on the linear interpolation along two axes. The axes are derived using a coordinate transformation algorithm to locate the quadrilateral of the four nearest profile points surrounding the unknown point. The interpolation computes the unknown value based on the average, by use of weights and distances, of the four nearest known values.

Brightness value (Digital Number) - a number representing a discrete gray level in an image.

Control - A combination of surveyed points and airborne GPS based collection, aerotriangulation solution, and inertial measurement unit (IMU) data considerations.

Cubic Convolution - a mathematical computation for the interpolation of an unknown value based on a third degree polynomial equation using surrounding known values.

Digital Orthoimage - a georeferenced digital image prepared from a perspective photograph, or other remotely-sensed data, in which displacement of objects in the image, due to sensor orientation and terrain relief, have been removed.

Framework - collection of basic geospatial data upon which users may collect, register or integrate geospatial information. Thematic categories comprising the framework include: geodetic control, digital orthoimagery, elevation, transportation, hydrography, governmental units, and cadastre (FGDC, 1995).

GeoTIFF - A TIFF based interchange format for georeferenced raster imagery

Global positioning system - A satellite-based radio-navigation system comprised of a constellation of twenty-four satellites and their supporting ground stations, used to obtain precise positions of targets on, or near, the surface of the Earth.

Inertial measurement unit – Comprised of accelerometers, gyros, and signal processing electronics, outputs high-accuracy acceleration and angular rate measurements in digital form to the control solution.

Metadata - Data about data. Textual information describing the content, quality, condition, and other characteristics of data.

Micron (μ) - The unit of length defined to be 0.000001 meter.

Nearest Neighbor - The mathematical computation for an unknown value based solely on the value of the nearest known value.

Overedge - Refers to data extending beyond the defined primary area of interest. This may be image data, or fill data required to “square” the image to achieve fixed record lengths.

Panchromatic (photography) - a term applied to photographic materials possessing sensitivity to all visible spectral colors, including red.

Pixel - "Picture element" is the ground area corresponding to a single element of a digital image data set.

Resample - the use of mathematical values on one cell-based structure based on values originally given on another structure. Methods include interpolation and extrapolation. See nearest neighbor, bilinear interpolation, and cubic convolution.

Root mean square error (RMSE)- RMSE is determined by calculating the deviations of points from their true position, summing up the measurements, and then taking the square root of the sum.

Sensor calibration – Details about the instrument(s) used.

Surface model – Elevation data comprised of both masspoints and breaklines that defines the earth surface. This data should cover the same geographic area as the final image product.