Chapter 2
Photogrammetric Accuracy Standards and Classifications

2-1. General

This Engineer Manual presents USACE photogrammetric mapping standards that have been established to specify the quality of the spatial data product (i.e., map) to be produced. These standards are drawn largely from the 31 March 1990 ASPRS Standards for Large-Scale Maps (ASPRS 1990). Parts 3 and 4, FGDC Geospatial Positioning Accuracy Standard (FGDC 1998) recognize the use of the ASPRS Standards for Large- Scale Mapping when mapping is larger than 1:20,000 scale. When mapping smaller than 1:20,000, Part 3, FGDC Geospatial Positioning Accuracy Standard (which is an update of the National Map Accuracy Standards (NMAS) 1947) shall be used.

a. Minimum accuracy standards. This chapter sets forth the accuracy standards to be used in USACE for photogrammetrically derived maps and related spatial data products. Map accuracies will follow guidelines established in the current FGDC Standards. Suggested requirements to meet these accuracy standards are given for critical aspects of the photogrammetric mapping and mensuration process, such as maximum flight altitudes, maximum photo enlargement ratios, C-Factor ratio limitations, and aerotriangulation adjustment criteria.

b. Map scales. Mapping accuracy standards are associated with the final development scale of the map or compilation scale, both the horizontal scale and vertical relief components. The use of CADD and GIS software allows the ready separation of planimetric features and topographic elevations to various layers, along with depiction at any scale. Problems arise when source scales are increased beyond their original values, or when the image is subjected to so-called "rubber sheeting." *It is therefore critical that these spatial data layers contain descriptor information (Metadata) identifying the original source target scale and designed accuracy*. **All USACE photogrammetric mapping projects shall include metadata fully compliant with the FGDC metadata requirements.** Sample metadata files are shown in Appendix E of this manual.

c. CADD vs GIS. Photogrammetric mapping data collection is generally a necessary but costly process. The decision regarding final formats (CADD vs GIS) of spatial data is not always clear cut. A portion of the time and cost in photogrammetric map production is the final format of the data sets. Factors that may affect the decision regarding CADD vs GIS include:

(1) Immediate and future uses of the spatial data sets collected.

(2) Immediate and future data analysis requirements for spatial data sets.

(3) Costs and time for each format requested.

(4) Project cost sharing and ownership.

Every attempt should be made to collect spatial data sets in the formats that will provide the most use and utility. GIS formatting costs can be minimized if the Contractor is aware of the request at the time of initial data collection. Many engineering, planning, and environmental projects can make use of and may require GIS capability in spatial data analysis. When planning a photogrammetric mapping project, both CADD and GIS formats may be required. Collection of the spatial data in both CADD and GIS will provide for the most utility of the spatial data sets and should be the first recommendation.

d. Mapping requirements. The specified accuracy of a geospatial data collection effort shall be sufficient to ensure that the map can be reliably used for the purpose intended, whether this purpose is an immediate or a future use. However, the accuracy of a map shall not surpass that required for its intended functional use. Specifying map accuracies in excess of those required for project design, construction, or condition reports is all too often performed. This could result in increased costs to USACE, local sponsors, or installations, and it may delay project completion. It is absolutely essential that mapping accuracy requirements originate from the functional and realistic accuracy requirements of the project. Photogrammetric mapping design criteria such as flight altitude, ground control survey accuracy, types of features typically collected, elevation model post spacing and optimum scanning resolution are determined from the design map scale and minimum contour interval. These requirements should be part of the Government and contractor project planning and cost estimate. The contract technical provisions (or delivery order Statement of Work (SOW) for indefinite delivery order contracts) should not be overly prescriptive and should not preclude contractor expertise and knowledge. USACE Commands should make the maximum use of **performance based specifications** for procuring photogrammetric mapping related services. These specifications should indicate desired end results and final products. Performance specifications for USACE photogrammetric projects should not mandate design criteria used to achieve the end results. Contract negotiations should establish actual project design criteria that will achieve the required map accuracy and end products. These criteria should be based upon final map accuracy requirements and mutually agreed upon design criteria that will achieve the map accuracy. **Prescriptive (procedural) specifications** should only be used for highly specialized or critical projects where only one method and/or unique equipment will be required to perform the work and create acceptable final products. **General guidance** on project-specific accuracy requirements is contained in this and later chapters.

e. Feature location tolerances. **Photogrammetric mapping accuracy is a function of the accuracy of a point on a map to its location on the earth.** Feature location tolerance is the positional accuracy of selected features relative to each other within the confines of a specific area and not the overall project or installation boundaries.. For example, two catch basins 60 m (200 ft) apart might need to be located 25 mm (0.1 ft) relative to each other, but need only be known to +30 m (+100 ft) relative to another catch basin 10 km (6 miles) away. Planning, design, and construction of typical USACE projects may require multiple feature location tolerances for project mapping requirements. In many instances, a feature may need to be located to a feature location tolerance well in excess of its plotted/scaled accuracy. Table 2-1 indicates recommended feature location tolerances of planimetric features. These feature tolerances are defined relative to adjacent points within the confines of a specific area, map sheet, or structure and not to the overall project or installation boundaries. **Photogrammetric map accuracy specifications should consider the functional requirements of the mapping and not feature location tolerance.**

f. Chapter precedence. The standards set forth in this chapter shall have precedence over numbers, figures, references, or guidance presented in other chapters of this manual.

2-2. Photogrammetric Mapping Standards

a. There are three recognized industry standards that can be used for specifying spatial mapping products and resultant accuracy compliance criteria:

(1) American Society for Photogrammetry and Remote Sensing (ASPRS). "ASPRS Accuracy Standards for Large-Scale Maps" (ASPRS 31 March 1993).

(2) Federal Geographic Data Committee (FGDC). "Geospatial Accuracy Standards, Part 3: National Standard for Spatial Accuracy (1998)," which is an update of Office of Management.

(3) Federal Geographic Data Committee (FGDC). "Geospatial Accuracy Standards, Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management (2001)."

Table 2-1
Recommended Surveying and Mapping Specifications for Military Construction, Civil Works, Operations, Maintenance, Real Estate, and Hazardous, Toxic, and Radioactive Waste (HTRW) Projects

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
MILITARY CONSTRUCTION (MCA, MCAF, OMA, OMAF):						
Design and Construction of New Facilities: Site Plan Data for Direct Input into CADD 2-D/3-D Design Files						
General Construction Site Plan Feature and Topo Detail	1:500/40 ft	100mm/0.1-0.5 ft	3rd-I	50mm/0.1-0.3ft	3rd	250mm/1ft
Surface/Subsurface Utility Detail	1:500/40 ft	100mm/0.2-0.5 ft	3rd-I	50mm/0.1-0.2ft	3rd	N/A
Building or Structure Design	1:500/40 ft	25mm/0.05-0.2 ft	3rd-I	50mm/0.1-0.3ft	3rd	250mm/1ft
Airfield Pavement Design Detail	1:500/40 ft	25mm/0.05-0.1 ft	3rd-I	25mm/0.05-0.1ft	2nd	250mm/0.5-1ft
Grading and Excavation Plans (Roads, Drainage, etc.)	1:500/30-100 ft	250mm/0.5-2 ft	3rd-I/II	100mm/0.2-1ft	3rd	500mm/1-2ft
Maintenance and Repair (M&R), or Renovation of Existing Structures, Roadways, Utilities, etc., for Design/Construction/ Plans and Specifications (P&S)	1:500/30-50 ft	100mm/0.1-0.5 ft	3rd-I	50mm/0.1-0.5ft	3rd	250mm/1ft
Recreational Site P&S (Golf Courses, Athletic Fields, etc.)	1:1000/100 ft	500mm/1-2 ft	3rd-II	100mm/0.2-2ft	3rd	500mm/2-5ft
Training Sites, Ranges, Cantonment Areas, etc.	1:2500/100-200 ft	500mm/1-5 ft	3rd-II	1,000mm/1-5ft	3rd	500mm/2ft
Installation Master Planning and Facilities Management Activities (Including AM/FM and GIS Feature Applications)						
General Location Maps for Master Planning Purposes	1:5000/100-400 ft	1,000mm/2-10 ft	3rd-II	1,000mm/1-10ft	3rd	1,000mm/ 2-10ft
Space Management (Interior Design/Layout)	1:250/10-50 ft	50mm/0.05-1 ft	Relative to Structure	N/A	N/A	N/A

Note: Footnotes 1 through 4 are repeated in headings on each page. Other footnotes are numbered sequentially through Table 2-1.

[1] Target map scale is that contained in CADD, GIS, and/or AM/FM layer, and/or to which ground topo or aerial photography accuracy specifications are developed. This scale may not always be compatible with the feature location/elevation tolerances required. In many instances, design or real property features are located to a far greater relative accuracy than that which can be scaled at the target (plot) scale, such as property corners, utility alignments, first-floor or invert elevations, etc. Coordinates/elevations for such items are usually directly input into a CADD or AM/FM data base.

[2] The map location tolerance (or precision) of a planimetric feature is defined relative to two adjacent points within the confines of a structure or map sheet, not to the overall project or installation boundaries. Relative accuracies are determined between two points that must functionally maintain a given accuracy tolerance between themselves, such as adjacent property corners; adjacent utility lines; adjoining buildings, bridge piers, approaches, or abutments; overall building or structure site construction limits; runway ends; catch basins; levee baseline sections; etc. The tolerances between the two points are determined from the end functional requirements of the project/structure (e.g., field construction/fabrication, field stakeout or layout, alignment, locationing, etc.).

[3] Horizontal and vertical control survey accuracy refers to the procedural and closure specifications needed to obtain/maintain the relative accuracy tolerances needed between two functionally adjacent points on the map or structure, for design, stakeout, or construction. Usually 1:5,000 Third-Order control procedures (horizontal and vertical) will provide sufficient accuracy for most engineering work, and in many instances of small-scale mapping or GIS mapping, Third-Order, Class II methods and Fourth-Order topo/construction control methods may be used. Base- or area-wide mapping control procedures shall be specified to meet functional accuracy tolerances within the limits of the structure, building, or utility distance involved for design or construction surveys. Higher order control surveys shall not be specified for area-wide mapping or GIS definition unless a definitive functional requirement exists (e.g., military operational targeting or some low-gradient flood control projects).

[4] (See note 2.) Some flood control projects may require better relative accuracy tolerances than those shown.

(Sheet 1 of 5)

Table 2-1 (Continued)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
MILITARY CONSTRUCTION (Continued)						
Installation Surface/Subsurface Utility Maps (As-builts; Fuel, Gas, Electricity, Communications, Cable, Storm Water, Sanitary, Water Supply, Treatment Facilities, Meters, etc.)	1:1000/50-100ft (DA) 1:500/50ft (USAF)	100mm/0.2-1ft	3rd-I	100mm/0.2ft	3rd	250mm/1ft
Architectural Drawings: Customary Inch-Pound Scale	Equivalent SI Ratio	N/A	N/A	N/A	N/A	N/A
Site Plans: 1" = 20 ' (Landscape Planting Plans)	1:250 1:500					
Floor Plans: 1/4" = 1' - 0" 1/8" = 1' - 0" 1/16" = 1' - 0"	1:50 1:100 1:200					
Roof Plan: (no smaller than) 1/16" = 1' - 0"	1:200					
Exterior Elevations: 1" or 1-1/2" = 1' - 0" 1/8" = 1' - 0" 1/16" = 1' - 0"	 1:10 1:100 1:200					
Interior Elevations: 1/4" = 1' - 0" 1/8" = 1' - 0"	1:50 1:100					
Cross Sections: 1/4" = 1' - 0" 1/8" = 1' - 0" 1/16" = 1' - 0"	1:50 1:100 1:50					
Wall Sections: 1/2" or 3/4" = 1' - 0"	 1:20					
Stair Details: 1" or 1-1/2" = 1' - 0" Detail Plans: 3" = 1' - 0" 1" or 1-1/2" = 1' - 0"	 1:10 1:5 1:10					
Area-/Installation-/Base-Wide Mapping Control Network to Support Overall GIS and AM/FM Development[5]	N/A	varies	3rd-I or 2nd-II	varies	2nd or 3rd	250-1000mm 1-10ft
Housing Management (Family housing, Schools, Boundaries, and Other Installation Community Services)	1:5000/100-400ft	10,000mm/ 10-50ft	4th	N/A	4th	N/A
Environmental Mapping and Assessments	1:5000/200-400ft	10,000mm/ 10-50ft	4th	N/A	4th	N/A
Emergency Services (Military Police, Crime/Accident Locations, Emergency Transport Routes, Post Security Zoning, etc.)	1:10000/400-2000ft	25,000mm/ 50-100ft	4th	N/A	4th	N/A
Cultural, Social, Historical (Other Natural Resources)	1:5000/400ft	10,000mm/ 20-100ft	4th	N/A	4th	N/A
Runway Approach and Transition Zones; General Plans/Section[6]	1:2500/100-200ft	2,500mm/5-10ft	3rd-II	2 500mm/2-5ft	3rd	1 000mm/5ft

[5] GIS raster or vector features generally can be scaled or digitized from any existing map of the installation. Typically a standard USGS 1:24,000 (1 in. = 2,000 ft) scale quadrangle map is adequate given the low relative accuracies needed between GIS data features, elements, or classifications. Relative or absolute GPS positioning (1m to 100m) may be adequate to tie GIS features where no maps exist. In general, a basic area- or installation-wide Second- or Third-Order control network is adequate for all subsequent engineering, construction, real estate, GIS, and/or AM/FM control.

[6] Typical requirements for general approach maps are 1:50,000 (H) and 1:1,000 (V); detail maps at 1:5,000 (H) and 1:250 (V).

(Sheet 2 of 5)

Table 2-1 (Continued)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
CIVIL WORKS DESIGN, CONSTRUCTION, OPERATIONS AND MAINTENANCE ACTIVITIES						
Site Plan for Design Memoranda, Contract Plans and Specifications, etc. C for Input to CADD 2-D/3-DDesign Files						
Locks, Dams, Flood Control Structures; Detail Design Plans	1:500/20-50ft	25mm/0.05-1ft	2nd-II	10mm/ 0.01-0.5ft	2nd/3rd	250mm/0.5-1ft
Grading/Excavation Plans	1:1000/100ft	1 000mm/0.5-2ft	3rd-I	100mm/0.2-1ft	3rd	1 000mm/1-5ft
Spillways, Concrete Channels, Upland Disposal Areas	1:1000/50-100ft	100 mm/0.1-2ft	2nd-II	100mm/0.2-2ft	3rd	1 000mm/1-5ft
Construction In-place Volume Measurement	1:1000/40-100ft	500mm/0.5-2ft	3rd-I	250mm/0.5-1ft	3rd	N/A
River and Harbor Navigation Projects: Site Plans, Design, Operation, or Maintenance of Flood Control Structures, Canals, Channels, etc. C for Contract Plans or Reports						
Levees and Groins (New Work or Maintenance Design Drawings)	1:1000/100ft	500mm/1-2ft	3rd-II	250mm/0.5-1ft	3rd	500mm/1-2ft
Canals and Waterway Dredging (New Work Base Mapping)[7]	1:1000/100ft	1 000mm/2ft	3rd-II	250mm/0.5ft	3rd	250mm/1ft
Canals and Waterway Dredging (Maintenance Drawings)	1:2500/200ft	1 000mm/2ft	3rd-II	250mm/0.5ft	3rd	250mm/1ft
Beach Renourishment/Hurricane Protection Projects	1:1000/100-200ft	1 000mm/2ft	3rd-II	250mm/0.5-1ft	3rd	250mm/1ft
Project Condition Reports (Base Mapping for Plotting Hydrographic Surveys: line maps or air photo plans)	1:2500/ 200-1,000ft	10 000mm/ 5-50ft	3rd-II	250mm/0.5-1ft	3rd	500mm/1-2ft
Revetment Clearing, Grading, and As-built Protection	1:5000/100-400ft	2 500mm/2-10ft	3rd-II	250mm/0.5-1ft	3rd	500mm/1-2ft
Geotechnical and Hydrographic Site Investigation Surveying Accuracies for Project Construction						
Hydrographic Contract Payment and P&S Surveys	1:2500/200ft	2 000mm/6ft (2DRMS)	N/A	250mm/0.5ft	N/A	250mm/1ft
Hydrographic Project Condition Surveys	1:2500/200ft	5 000mm/16ft (2DRMS)	N/A	500mm/1.0ft	N/A	250mm/1ft
Hydrographic Reconnaissance Surveys	C	0.15km/500ft (2DRMS)	N/A	500mm/1.5ft	N/A	250mm/1ft
Geotechnical Investigative Core Borings/Probings/etc.	C	5 000mm/5-15ft	4th	50mm/0.1-0.5ft	3rd or 4th	N/A
General Planning and Feasibility Studies, Reconnaissance Reports, Permit Applications, etc.	1:2500/100-400ft	1 000mm/2-10ft	3rd-II	500mm/0.5-2ft	3rd	1 000mm/ 2-10ft
GIS Feature Mapping--Civil Works Projects						
Area/Project-Wide Mapping Control Network to Support Overall GIS Development	N/A	Varies 1:5000	2nd-I or 2nd-II	Varies	2nd	1 000mm/ 1-10ft
Soil and Geologic Classification Maps, Well Points	1:5000/400ft	10 000mm/ 20-100ft	4th	N/A	4th	N/A

[7] Table refers to base maps upon which subsurface hydrographic surveys are plotted, not to hydrographic survey control.

(Sheet 3 of 5)

Table 2-1 (Continued)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
CIVIL WORKS DESIGN, CONSTRUCTION, OPERATIONS AND MAINTENANCE ACTIVITIES ACTIVITIES (Continued)						
Cultural and Economic Resources, Historic Preservation	1:10000/1,000ft	10 000mm/ 50-100ft	4th	N/A	4th	N/A
Land Utilization GIS Classifications; Regulatory Permit General Locations	1:5000/400-1,000ft	10 000mm/ 50-100ft	4th	N/A	4th	N/A
Socio-economic GIS classifications	1:10,000/1,000ft	20 000mm/ 100ft	4th	N/A	4th	N/A
Land Cover Classification Maps	1:5000/400-1,000ft	10 000mm/ 50-200ft	4th	N/A	4th	N/A
Archeological or Structure Site Plans & Details (Including Non-topographic, Close Range, Photogrammetric Mapping)	1:10/0.5-10ft	5mm/0.01-0.5ft	2nd I/II	5mm/ 0.01-0.5fft	2nd	100mm/0.1-1ft
Structural Deformation Monitoring Studies/Surveys[8]						
Reinforced Concrete Structures (Locks, Dams, Gates, Intake Structures, Tunnels, Penstocks, Spillways, Bridges, etc.)	Large-scale vector movement diagrams or tabulations	10mm/0.03ft (long term)	N/A[9]	2mm/0.01ft	N/A[9]	N/A
Earth/Rock Fill Structures (Dams, Floodwalls, Levees, etc.) (slope/crest stability & alignment)		30mm/0.1ft (long term)	N/A	15mm/0.05ft	N/A	N/A
Crack/joint & deflection measurements (precision micrometer)	tabulations	0.2mm/0.01inch	N/A	N/A	N/A	N/A
Flood Control and Multipurpose Project Planning, Floodplain Mapping, Water Quality Analysis, and Flood Control Studies	1:5000/400-1,000ft	10 000mm/ 20-100ft	3rd-I	100mm/0.2-2ft	2nd or 3rd	1 000mm/2-5ft
Federal Emergency Management Agency Flood Insurance Studies	1:5000/400ft	10 000mm/20ft	3rd-I	250mm/0.5ft	3rd	1 000mm/4ft
REAL ESTATE ACTIVITIES (ACQUISITION, DISPOSAL, MANAGEMENT,AUDIT)[10]						
Tract Maps, Individual, Detailing Installation or Reservation Boundaries, Lots, Parcels, Adjoining Parcels, and Record Plats, Utilities, etc.	1:1000/50-400ft[11]	10mm/0.05-2ft	3rd-I/II	100mm/0.1-2ft	3rd	1 000mm/1-5ft
Condemnation Exhibit Maps	1:1000/50-400ft	10mm/0.05-2ft	3rd-I/II	100mm/0.1-2ft	3rd	1 000mm/1-5ft
Guide Taking Lines (for Fee and Easement Acquisition) Boundary Encroachment Maps	1:500/20-100ft	50mm/0.1-1ft	3rd-I/II	50mm/0.1-1ft	3rd	250mm/1ft
Real Estate GIS or LIS General Feature Mapping Land Utilization and Management Forestry Management Mineral Acquisition	1:5000/200-1,000ft	10 000mm/ 50-100ft	4th	N/A	4th	N/A
General Location or Planning Maps	1:24,000 (USGS)	10 000mm/ 50-100ft	N/A	5 000mm/5-10ft	3rd	2 000mm/ 5-10ft
Easement Areas and Easement Delineation Lines	1:1000/100ft	50mm/0.1-0.5ft	3rd-I/II	50mm/0.1-0.5ft	3rd	C

[8] Long-term structural movements measured from points external to the structure may be tabulated or plotted in either X-Y-Z or by single vector movement normal to a potential failure plane. Reference EM 1110-2-4300, EM 1110-2-1908, and EM 1110-1-1004 for stress-strain, pressure, seismic, and other precise structural deflection measurement methods within/between structural members, monoliths, cells, embankments, etc.

[9] Accuracy standards and procedures for structural deformation surveys are contained in EM 1110-1-1004. Horizontal and vertical deformation monitoring survey procedures are performed relative to a control network established for the structure. Ties to the National Geodetic Reference System or National Geodetic Vertical Datum of 1929 are not necessary other than for general reference, and then need only USACE Third-Order connection.

[10] Real property surveys shall conform to local/state minimum technical standards and/or recognized practices, and where prescribed by law or code.

[11] A 1:1,200 (1-in. = 100-ft) scale is recommended by ER 405-1-12. Smaller scales should be on even 30-m (100-ft) increments.

(Sheet 4 of 5)

Table 2-1 (Concluded)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
HAZARDOUS, TOXIC, & RADIOACTIVE WASTE (HTRW) SITE INVESTIGATION, MODELING, AND CLEANUP						
General Detailed Site Plans (HTRW Sites, Asbestos, etc.)	1:500/5-50ft	100mm/0.2-1ft	2nd-II	50mm/ 0.1-0.5ft	2nd or 3rd	100mm/0.5-1ft
Subsurface Geotoxic Data Mapping (Modeling)	1:500/20-100ft	1 000mm/1-5ft	3rd-II	500mm/1-2ft	3rd	500mm/1-2ft
Contaminated Ground Water Plume Mapping (Modeling)	1:500/20-100ft	1 000mm/2-10ft	3rd-II	500mm/1-5ft	3rd	500mm/1-2ft
General HTRW Site Plans, Reconnaissance Mapping	1:2500/50 - 400	5 000mm/2-20ft	3rd-II	1 000mm/ 2-20ft	3rd	1 000mm/2-5ft
EMERGENCY OPERATION MANAGEMENT ACTIVITIES						
(Use basic GIS database requirements defined above)						
(Sheet 5 of 5)						

Each of these standards has application to different types of functional products, ranging from wide-area small-scale mapping (FGDC Geospatial Accuracy Standards, Part 3 (FGDC 1998)) to large-scale engineering design (ASPRS Accuracy Standards for Large-Scale Maps and FGDC Geospatial Accuracy Standards, Part 4 (FGDC 1998)). Their resultant accuracy criteria (i.e., spatial errors in X-Y-Z), including QC compliance procedures, do not differ significantly from one another. In general, use of any of these standards for a photogrammetric mapping contract will result in a quality product. The operational philosophy of many photogrammetric mapping offices is oriented toward ASPRS and National Map Accuracy Standards, Office of Management and Budget (OMB). Notwithstanding, Contractors are obligated to meet accuracies referenced in this document as USACE Photogrammetric Mapping Standards if specified in a contract.

b. OMB Circular No. A-119, “Federal Participation in the Development and Use of Voluntary Standards,” prescribes that Federal agencies maximize use of industry standards and consensus standards established by private voluntary standards bodies, in lieu of Government-developed standards. Voluntary industry standards shall be given preference over nonmandatory Government standards. When industry standards are nonexistent, inappropriate, or do not meet a project's functional requirement, DoD, Army, USACE, or FGDC standards may be specified as criteria sources. Specifications for surveying and mapping shall use industry consensus standards established by national professional organizations, such as the ASPRS, the American Society of Civil Engineers (ASCE), the American Congress on Surveying and Mapping (ACSM), or the American Land Title Association (ALTA). Technical standards established by state boards of registration, especially on projects requiring licensed surveyors or mappers, shall be followed when legally applicable. Commands shall not develop or specify local surveying and mapping standards where industry consensus standards or Army standards exist.

2-3. USACE Photogrammetric Mapping Standard

The USACE accuracy standard for photogrammetric mapping is modeled after the ASPRS Accuracy Standards for Large-Scale Maps and Part 4 of the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards (1998). When applicable to a specific photogrammetric mapping process or product, ASPRS standard will be the USACE standard. This standard was developed for the production mapping products with spatial accuracies typically required for engineering projects designed by the USACE. This standard is intended for site plan development work involving mapping scales larger than 1:20,000, usually in the range of 1 in. = 40 ft to 1 in. = 1,667 ft. Its primary advantage over other standards is that it contains more definitive statistical map testing criteria, which, from a contract administration standpoint, is desirable. It also is applicable to conventional surveying topographic site development work. This standard, like most other mapping standards, defines map accuracy by comparing the mapped location of selected well defined points to their "true" location, as determined by a more accurate, independent field survey. When no independent check is feasible or practicable, a map's accuracy may be estimated based on the accuracy of the technique used to locate mapped features (e.g., GPS, total station, plane table, etc.) For small-scale general location mapping work (i.e., scales smaller than 1:20,000), the "United States National Map Accuracy Standards" (Bureau of the Budget 1947) and "U.S. National Cartographic Standards for Spatial Accuracy" are perhaps the most widely used standards and are recommended for USACE small-scale mapping.

a. Application of standards. The objective of the USACE photogrammetric standards is twofold:

(1) To help ensure that the topographic map accuracy standards or geospatial database accuracy will be met during the production process.

(2) To help ensure that contractual deliverables other than maps, such as aerial photographs, ground control, etc., will possess quality of the required degree.

b. Map accuracy subclassifications. The ASPRS Standard classifies a map as statistically meeting a certain level of accuracy. Its primary advantage over other standards for large-scale mapping is that it contains more definitive statistical map testing criteria. Using guidance in Tables 2-2 and 2-3, specifications for site plans need only indicate the ASPRS map class, target scale (horizontal map scale), and contour interval. Three map accuracy classifications are prescribed in the ASPRS Standards. These classes are discussed in paragraph 2-4a. Lower classifications will be more economical, albeit less accurate. The project engineer/manager coupled with the USACE photogrammetric mapping specialist must determine the specific map accuracy requirement and class for a given project based on the functional requirements. The accuracy class must be shown on all final drawings/design files.

Table 2-2
ASPRS Planimetric Feature Coordinate Accuracy Requirement (Ground X or Y) for Well-Defined Points

Target Map Scale	ASPRS Limiting RMSE in X or Y (Meters)			Target Map Scale	ASPRS Limiting RMSE in X or Y (Feet)			
Ratio m/m	Class 1	Class 2	Class 3	1"=x ft	Ratio, ft/ft	Class 1	Class 2	Class 3
1:500	0.125	0.25	0.375	40	1:480	0.4	0.8	1.2
1:1,000	0.25	0.50	0.75	50	1:600	0.5	1.0	1.5
1:2,000	0.50	1.00	1.5	60	1:720	0.6	1.2	1.8
1:2,500	0.63	1.25	1.9	100	1:1,200	1.0	2.0	3.0
1:3,000	0.75	1.5	2.25	200	1:2,400	2.0	4.0	6.0
1:4,000	1.0	2.0	3.0	300	1:3,600	3.0	6.0	9.0
1:5,000	1.25	2.5	3.75	400	1:4,800	4.0	8.0	12.0
1:8,000	2.0	4.0	6.0	500	1:6,000	5.0	10.0	15.0
1:9,000	2.25	4.5	6.75	600	1:7,200	6.0	12.0	18.0
1:10,000	2.5	5.0	7.5	800	1:9,600	8.0	16.0	24.0
1:16,000	4.0	8.0	12.0	1,000	1:12,000	10.0	20.0	30.0
1:20,000	5.0	10.0	15.0	1,667	1:20,000	16.7	33.0	50.0

c. Use of ASPRS Standards for ground survey mapping. The ASPRS Standards are also applicable to large-scale site plan mapping performed by plane table or electronic total station techniques. This work may either supplement the aerial mapping work (e.g., surface or subsurface utility details) or be of a scale too large for aerial mapping (generally larger than 1 in. = 40 ft).

d. Compliance tests. Tests for compliance with the ASPRS and other map accuracy standards are discussed in more detail in Chapter 2, paragraph 2-4*d*, and Chapter 3, paragraph 3-7. Maps found compliant with a particular standard shall have a statement indicating that standard. The compliance statement shall refer to the data of lowest accuracy depicted on the map. As a result of the high cost of field testing, not all deliverables should be tested. In such cases, the statement should clearly indicate that the procedural mapping

Table 2-3
ASPRS Topographic Elevation Accuracy Requirement for Well-Defined Points

ASPRS Limiting RMSE in Meters							ASPRS Limiting RMSE in Feet						
Target Contour Interval	Topographic Feature Points			Spot or Digital Terrain Model Elevation Points			Target Contour Interval	Topographic Feature Points			Spot or Digital Terrain Model Elevation Points		
Meters	Class1	Class 2	Class 3	Class 1	Class 2	Class3	Feet	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
0.5	0.17	0.33	0.50	0.08	0.16	0.25	1	0.33	0.66	1.0	0.17	0.33	0.5
1	0.33	0.66	1.0	0.17	0.33	0.5	2	0.67	1.33	2.0	0.33	0.67	1.0
2	0.67	1.33	2.0	0.33	0.67	1.0	3	1.0	2.0	3.0	0.50	1.00	1.50
							4	1.33	2.67	4.0	0.67	1.33	2.0
4	1.33	2.67	4.0	0.67	1.33	2.0	5	1.67	3.33	5.0	0.83	1.67	2.5
5	1.67	3.33	5.0	0.83	1.67	2.5	10	3.33	6.66	10.0	1.67	3.33	5.0

specifications were designed and performed to meet a certain ASPRS map classification but that a rigid compliance test was not performed. Published maps and geospatial databases whose errors exceed those given in a standard should indicate in their legends or metadata files that the map is not controlled and that dimensions are not to scale. This accuracy statement requirement is especially applicable to databases compiled from a variety of sources containing known or unknown accuracy reliability. Generally, overall map accuracy is affected by each of the main processes used in photogrammetric map production. Aerial photography, supporting ground control, aerotriangulation, and feature collection are the main processes. Deviation from standard guidance in subsequent chapters in this manual regarding these processes can result in degradation of map accuracy. The effect of noncompliance is not always intuitive and is often map scale-and/or process-dependent. Map accuracy should begin in the scope of work development. The scope of work should follow the guidelines established in this manual without being overly prescriptive. Quality Assurance (QA) testing should involve review for compliance of each process as the project proceeds. Accuracy testing of mapping products should be performed within a fixed time period after delivery. The contractor selection process should consider contractor's QC processes. The Government should only perform minimal, selected QA testing. QA should focus on whether the contractor meets the required performance specification (e.g., map accuracy). In accordance with the ASPRS Standard and class, the horizontal and vertical accuracies of a map are checked by comparing measured coordinates or elevations from the map (at its intended target scale) with spatial values determined by a check survey of higher accuracy. The check survey should be at least twice as accurate as the map feature tolerance given in the ASPRS tables.

2-4. ASPRS Accuracy Standards for Large-Scale Maps

In March 1990, the Professional Practicing Division, ASPRS, approved a set of standards as guidelines for large-scale mapping (Appendix D). These standards have been designed for large-scale planimetric and topographic maps prepared for engineering applications and other special purposes. ASPRS standards defines map accuracy by comparing the mapped location of selected well-defined points to their Aactual@ location as determined by a more accurate, independent field survey. Its primary advantage over other standards is that it contains more definitive statistical map testing criteria, which, from a contract administration standpoint, is desirable. The ASPRS standard has application to different types of mapping, ranging from wide-area, small-scale, GIS mapping to large-scale construction site plans. The ASPRS standards shall be used for USACE large-scale mapping projects. The ASPRS standards are synopsized below.

a. Map classes. Three map accuracy classes are defined. Class 1 maps are the most accurate. Class 2 maps have twice the root mean square error (RMSE) of a Class 1 map; Class 3 maps have thrice the RMSE of a Class 1 map. RMSE is defined to be the square root of the average of the squared discrepancies. The discrepancies are the differences in coordinate or elevation values as derived from the map and as determined by an independent survey of higher accuracy (check survey). The RMSE is defined in terms of feet or meters at ground scale rather than in inches or millimeters at the target map scale. This results in a linear relationship between RMSE and target map scale; as map scale decreases, the RMSE increases linearly. The RMSE is the cumulative result of all errors including those introduced by the processes of ground control surveys, map compilation, and final extraction of ground dimensions from the target map.

b. Horizontal accuracy criteria. The planimetric standard makes use of the RMSE. The limiting horizontal RMSEs shown in Table 2-2 are the maximum permissible RMSEs established by this standard. These limits of accuracy apply to well-defined points only.

c. Vertical accuracy criteria. Vertical accuracy is defined relative to the required contour interval (CI) for a map. In cases where only digital terrain models (DTM) or digital elevation models (DEM) are being generated, an equivalent CI must be specified based on the required digital point (spot) elevation accuracy. The contours themselves may be generated later using CADD software routines. The vertical standard also uses the RMSE, but only for well-defined features between contours containing interpretative elevations, or spot elevation points. Contours in themselves are not considered as well-defined feature points. The RMSE for Class 1 contours is one-third of the CI. The RMSE for Class 1 spot heights is one-sixth of the CI. Class 2 and Class 3 accuracies are twice and thrice those of Class 1, respectively. Testing for vertical map compliance is also performed by independent, higher accuracy ground survey methods, such as differential leveling. Table 2-3 summarizes the limiting vertical RMSEs for well-defined points, as checked by independent surveys at the full (ground) scale of the map.

d. Map accuracy testing. Map accuracy testing can be costly and time consuming. One or more sheets (or segments of a design file) may be tested for compliance. The decision whether to check photogrammetric mapping products rests with the Contracting Officer or his designated representative and is dependent on numerous factors, such as intended design work, available personnel, known contractor capabilities, and personnel resources available for the test. Every attempt should be made to review and check major phases of the mapping process (i.e., project planning, ground control, aerotriangulation, and compilation) as they are completed. Additional ground survey checks of map feature accuracy should be limited and in most cases eliminated. The Government should rely heavily on the Contractor's QC program and procedures to check for and catch blunders. **When it becomes necessary to perform independent QA checks for map accuracy, the USACE will follow the ASPRS standards for map accuracy tests.** Horizontal and vertical accuracy is to be checked by comparing measured coordinates or elevations from the map (at its intended target scale) with coordinates determined by a check survey of higher accuracy. The check survey should be at least twice as accurate as the map feature tolerance given in the ASPRS tables, with a minimum of 20 points tested. Maps and related geospatial databases complying with a required standard shall have a statement indicating that standard. The compliance statement shall refer to the data of lowest accuracy depicted on the map, or, in some instances, to specific data layers or levels. The statement shall clearly indicate the target map scale at which the map or feature layer was developed. Because of the high cost of field testing, not all deliverables will be physically tested. In such cases, the statement shall clearly indicate that the procedural mapping specifications were designed and performed to meet a certain ASPRS map classification, but that a rigid compliance test was not performed. Published maps and geospatial databases with errors exceeding those given in a standard shall indicate in their legends or metadata files that the map is not controlled and that dimensions are not to scale. This accuracy statement requirement is especially applicable to GIS databases that may be compiled from a variety of sources containing known or unknown accuracy reliability.

(1) For horizontal points, the check survey should produce a standard deviation equal to or less than one-third of the limiting RMSE selected for the map. This means that the relative distance accuracy ratio of the check survey must be less than one-third that of the limiting RMSE, expressed as a function of the distance measured across an agreed upon typical map sheet or digital file equivalent (not overall project or design file) diagonal. **For example,** given a 1-in. = 50-ft target scale with a required horizontal feature accuracy of 0.5 ft (i.e., Table 2-2, Class 1 accuracy) and a typical diagonal distance of 40 in. across a typical map sheet, the check survey should have a relative accuracy of 1:12,000, or Second-Order, Class 2 (50 ft/in. by

40 in./0.5 ft/3). This accuracy level is constant for all scales plotted on a standard drawing sheet with approximately a 40-in. dimension.

(2) Only the dimensions of a typical sheet or digital file equivalent, not the overall project or design file dimensions, are used to compute relative line accuracies. This is true regardless of whether or not the data are contained in an overall digital design file. The critical parameter for engineering and construction is relative to the accuracy of map features within the range of a drawing/sheet.

(3) For vertical points, the check survey (i.e., Global Positioning System (GPS), differential leveling, or electronic total station trig elevations) should produce an RMSE not greater than 1/20th of CI, expressed relative to the longest diagonal dimension of a standard drawing sheet. The map position of the ground point may be shifted in any direction by an amount equal to twice the limiting RMSE in horizontal position. Ground survey techniques considered acceptable for check surveys should include GPS, differential leveling, or total station trig elevations. The RMSE requirement for the check survey should direct the survey techniques utilized. Again, as with horizontal evaluation, vertical check survey accuracies are relative to the area on a given map sheet, not to the overall project dimension.

(4) The same survey datums must be used for both the mapping and check surveys. Care should be taken to ensure that datums are consistent and that any datum conversion was calculated properly.

(5) Refer to Chapter 3, paragraph 3.7, Quality Control/Quality Assurance, for additional details on map testing criteria.

e. Checkpoints. As mentioned earlier, checkpoints should be confined to well-defined features. Depending upon map scale, certain features will be displaced for the sake of map clarity. These points should not be used unless the rules for displacement are well known and can be counteracted. Test points should be well distributed over the map area. Any checkpoint whose discrepancy exceeds three times the limiting RMSE should be corrected before the map is considered to meet the standard.

f. Compliance statement. Maps (or the appropriate digital design file descriptor level) produced to meet the USACE standard shall include the following statement:

THIS MAP WAS COMPILED TO MEET THE USACE STANDARD FOR CLASS *[__] MAP ACCURACY

If the map was field checked and compliant, the following additional statement shall be added:

THIS MAP WAS CHECKED AND CONFORMED TO THE USACE STANDARD FOR CLASS *[__] MAP ACCURACY

For digital products, the descriptor level should also contain the original target mapping scale along with the absolute horizontal and vertical accuracies intended or checked.

2-5. Typical Mapping Scales, Contour Intervals, and Accuracy Classifications for USACE Functional Applications

Table 2-1 depicts typical mapping parameters for various USACE engineering, construction, and real estate mapping applications. The table is intended to be a general guide in selecting a target scale for a specific project; numerous other project-specific factors may dictate variations from these general values. The table does not apply exclusively to photogrammetric mapping activities. Some of the required surveying and mapping accuracies identified exceed those obtainable from photogrammetry and may need to be obtained using conventional surveying techniques. Selection of an appropriate CI is extremely site-dependent and will directly impact the mapping costs since the photo negative scale (and resultant model coverage and ground survey control) is determined as a function of this parameter. Table 2-1 may be used as general guidance in selecting a CI (or DTM elevation accuracy, as applicable). See also additional guidance in subsequent chapters dealing with photo mapping planning and cost estimating.

2-6. Supplemental USACE Photogrammetric Mapping Criteria

The following criteria shall be followed (and/or referenced) in preparing contract specifications or delivery order scopes of work for photogrammetric mapping services.

a. Non-International System of Units (SI)/SI conversion. Conversions between non-SI units and SI units of measure shall be as follows:

(1) 1 in. = 25.4 mm exactly

(2) 1 International Foot = 0.3048 m exactly

(3) 1 U.S. Survey Foot = 1,200/3,937 m exactly

b. Maximum enlargement for map compilation from negative to map scale. Enlargement factors are used during the planning phases of a project to establish an acceptable flight height that will produce an expected photogrammetric map horizontal accuracy. These enlargement factors are based on assumptions regarding the photogrammetric mapping process used by a specific mapping office. These assumptions are based on equipment used, climatic conditions during the flight, and expertise of personnel performing the processes. The maximum enlargement from original negative scale to final map scale shall conform to Table 2-4.

Table 2-4
Maximum Enlargement Ratios from Photographic Scale to Map Scale

	Maximum Enlargement Photo to Map	
Instrument Type	Map Class	Planimetric Map Enlargement
Analytical Stereoplotter	1	7
	2	8
	3	9
Softcopy Workstation	1	7
	2	8
	3	9

Note: Topographic enlargement limitations are a function of the contour interval and C-Factor.

c. C-Factor ratios. C-Factor (Contour Factor) has been a concept of determining appropriate flight altitude for vertical mapping from aerial photography for at least half a century. It is an empirical concept and subject to wide latitude of bias based on a number of variables, major among which are:

(1) Resolution and image definition of the aerial photograph affected by such factors as silver grain size, altitude, haze, sun angle, and brightness.

(2) Photographic lab processing of negatives and film transparencies.

(3) Sophistication and precision of the optical and mechanical system of the stereo mapping instrumentation.

(4) Integrity of a combination of ground control (GPS and/or conventional surveys), number and spacing of ground control points, airborne GPS hardware and post processing software, and aerotriangulation procedures and software.

(5) Reliability of digital data collection based on experience and visual depth perception of the stereoplotter operator.

C-Factor = Height of flight above mean terrain / Contour Interval

An **assumed C-Factor ratio** is used during the planning of a photogrammetric project to establish an acceptable flight height for an expected map vertical accuracy. Each office that produces photogrammetric maps has a different mix of equipment, personnel, and experience. **Assumed C-Factor ratios** are based on experience developed from similar projects. Photogrammetric maps produced with similar equipment and personnel and under the same general climatic circumstances should produce an ***actual C-Factor*** within a fairly tight range. The same final map vertical accuracy may be achieved with different equipment, personnel, and processes, and the *actual C-Factor* would fall within a broader range as shown in Table 2-5. The *actual C-Factor* can only be known after a project is completed and the accuracy tested. Planning of a photogrammetric mapping project should consider the **Assumed C-Factor Ratio Ranges** indicated in Table 2-5. Table 2-6 indicates photographic negative scales and flight altitudes that are compatible with the low end of the Assumed C-Factor Ratio Ranges for a specific map class as shown in Table 2-5.

Table 2-5
Assumed C-Factor Ratio Ranges (Denominator)

Stereoplotter	Class 1	Class 2	Class 3
Analytical	2,000	2,200	2,500
Softcopy	2,000	2,200	2,500

d. Minimum negative scales for planimetry. Table 2-7 depicts the minimum allowable negative scale (and related flight altitude for a 6-in. focal length camera) for a given target mapping scale. These minimum scales are based on the enlargement ratio for a given map class prescribed Table 2-4, and the Assumed C-Factor Ratio indicated for a map class in Table 2-5. The minimum scales are intended for large-scale engineering and design site plan mapping work. Enlargement factors are related to and dependent upon photogrammetric equipment, expertise, and personnel utilized throughout the photogrammetric mapping process. These variables may differ with different contractors. The Government should make use of individual contractor's experience as it relates to negative scale appropriate C-Factor on final map accuracy. The photographic negative scale and flight altitude used for a project should be established based on an individual contractor's experience and fall within the ranges noted in Table 2-4. The design negative scale may be computed by multiplying the target scale times the maximum allowable enlargement ratio prescribed in Table 2-4. Once it is decided which enlargement factor will be used in the project design, Table 2-7 should be checked to ensure agreement.

e. Minimum negative scale for topographic development. The negative scales and flight altitudes shown in Table 2-6 are based on the Assumed C-Factors shown in Table 2-5. The minimum negative scales in Table 2-6 shall be used relative to the vertical contour accuracy intended for the product. These negative scales, along with limitations based on the planimetric component, will be used in determining the optimum negative scale for a project. The limiting negative scales are computed based on the prescribed Assumed C-factor ratio chosen from Table 2-5 (multiplied by the CI and divided by 6).

Table 2-6
Minimum Negative Scale and Maximum Flight Altitudes for Topographic Development Negative Scale in English Feet and Flight Height in English Feet Above Mean Terrain Assumed C-Factor = 2,000

	Negative Scale in Inches to Feet (Altitude Above Mean Terrain in Feet)		
Contour Interval	**Class 1**	**Class 2**	**Class 3**
1 ft	330 (2,000)	370 (2,200)	420 (2,500)
0.5 m	550 (3,300)	600 (3,600)	680 (4,100)
2 ft	670 (4,000)	730 (4,400)	830 (5,000)
1 m	1,100 (6,600)	1,200 (7,200)	1,370 (8,200)
3 ft	1,000 (6,000)	1,110 (6,600)	1,250 (7,500)
4 ft	1,330 (8,000)	1,470 (8,800)	1,670 (10,000)
5 ft	1,670 (10,000)	1,830 (11,000)	2,390 (12,500)
2 m	2,170 (13,000)	2,400 (14,400)	2,730 (16,400)
10 ft	3,333 (20,000)	3,667 (22,000)	4,167 (25,000)

Table 2-7
Minimum Negative Scales and Maximum Flight Altitudes for Planimetric Mapping in English Feet (C-Factor assumed = 2,000)

	Negative Scale in Inches to Feet (Altitude Above Mean Terrain in Feet)		
TargetMap ScaleRatio	**Class 1**	**Class 2**	**Class 3**
1:500	292 (1,750)	333 (2,000)	375 (2,250)
1:600	350 (2,100)	400 (2,400)	450 (2,700)
1:1,000	583 (3,500)	667 (4,000)	750 (4,500)
1:1,200	700 (4,200)	800 (4,800)	900 (5,400)
1:2,000	1,167 (7,000)	1,333 (8,000)	1,500 (9,000)
1:2,400	1,400 (8,400)	1,600 (9,600)	1,800 (10,800)
1:2,500	1,458 (8,750)	1,667 (10,000)	1,875 (11,250)
1:4,800	2,800 (16,800)	3,200 (19,200)	3,600 (21,600)
1:5,000	2,917 (17,500)	3,333 (20,000)	3,750 (22,500)
1:9,600	5,600 (33,600)	6,400 (38,400)	7,200 (21,600)
1:10,000	5,833 (35,000)	6,667 (40,000)	7,500 (45,000)
1:12,000	7,000 (42,000)	8,000 (48,000)	9,000 (54,000)
1:16,000	9,333 (55,998)	10,667 (64,002)	12,000 (72,000)
1:20,000	11,667 (70,000)	13,333 (80,000)	15,000 (90,000)

Notes:
1. Minimum negative scale in feet per inch shown above maximum flight altitude in feet shown in brackets.
2. Capturing aerial photography above 22,000 ft may require specially equipped aircraft. The additional equipment and time required may equate to significant additional costs. When target map scales above 1:5,000 are required, consideration should be given to flying at an altitude below 22,000 ft.

f. Photo control survey standards and specifications. Ground survey control for photogrammetry can become a costly portion of a mapping project. Conventional traversing and level loops through difficult terrain can drastically affect the cost and time to establish ground control. Every attempt should be made to keep these costs and subsequent time frames to a minimum without jeopardizing the mapping quality and accuracy. The unique circumstances of a particular project should be considered in planning the tools that will be used to establish required ground control. Conventional traversing, levels, and GPS and Airborne GPS should all be considered as viable tools to establish ground control. Generally a combination of these tools will be required. The decision to use each of the tools should be based on accuracy required, time, cost and project specific conditions. Generally, industry standards should be used in deciding amount and placement of ground control. The tools and methods to be used in a photo control survey project should be the decision of the survey contractor. Ground survey contracts, task orders, and subsequent scopes of work should be performance oriented (i.e., survey control will be compatible with final map scale accuracy) and should not unnecessarily mandate procedures. Contractors are selected based partially on technical competence and when having full understanding of the intended use of the survey data requested should be able to plan and produce a product that meets the requirements. The accuracy requirement for the mapping project should be specified and the contractor should propose a minimum control plan that will achieve the required accuracy. Recommended horizontal and vertical control survey accuracy requirements are stated in Table 2-1. **In general, GPS technology should be able to achieve these results for both horizontal and vertical ground control.** The decision to check GPS derived horizontal and or vertical positions for a specific project should be project specific and not be mandated in the contract by a specified checking procedure. Ground survey requirements and planning information is addressed in other chapters in this manual. Detailed guidance regarding ground survey accuracy requirements and procedures is provided in Chapter 6 of this manual.

g. Aerotriangulation accuracy standards. Aerotriangulation may be accomplished with diapositives and stereoplotters, total softcopy workstation/scanning methods, or a combination of the two methods. The requirement and criteria will be the horizontal and vertical accuracy achieved. See Chapter 8 for more information regarding methods and processes involved in aerotriangulation. Aerotriangulation accuracy for each class of map and orthophotograph shall conform to Table 2-8.

Table 2-8
Aerotriangulation Accuracy Criteria

		Allowable Error at Control and Test Points			
		Horizontal		**Vertical**	
Map Class	Aerotriangulation Method	**RMSE**	**Max.**	**RMSE**	**Max.**
1	**Fully Analytical or Softcopy Workstation**	**H/10,000**	**3 RMSE**	**H/9,000**	**3 RMSE**
2	**Fully Analytical or Softcopy Workstation**	**H/8,000**	**3 RMSE**	**H/6,000**	**3 RMSE**
3	**Fully Analytical or Softcopy Workstation**	**H/6,000**	**3 RMSE**	**H/4,000**	**3 RMSE**

2-7. USACE Orthophoto and Orthophoto Map Accuracy Standards

This section sets forth the standards for orthophotos and orthophoto maps. Orthophoto production is generally achieved by digital processes. High resolution scanning of diapositives or negative film coupled with the merging of DEM or DTM data utilizing acceptable rectification algorithms are the main processes involved in digital orthophoto production. **Photo enlargements, simply rectified images and rubber sheeting are photographic products and do not comply with the basic procedures involved in photogrammetry that produce accurate maps from aerial photography.** Items that affect digital orthophoto accuracy include: scanner quality and geometric accuracy, scanning pixel size, photography negative scale, and DTM resolution and accuracy. Each orthophoto shall meet the quality and precision specified in the contract. USACE standards for digital orthophoto mapping will conform to the accuracy standards specified below. Additional orthophoto mapping criteria are found in Chapter 10.

a. Photographic detail. The ground surface, vegetation, culture, planimetry, and all other details shall be clearly discernable. The photography scale must be designed for maximum feature discernability. The level of discernible detail is dependant on the pixel resolution of the scanned imagery and the desired final plot scale of the orthophoto.

b. Accuracy. Digital orthophotographs can have both a relative and absolute accuracy. The design plot scale (i.e., 1=500 planimetric feature scale) of the digital orthophotograph determines the relative accuracy. Enlargement of source photography for orthophotographs is dependent upon orthophoto design plot scale requirements and the type of terrain and shall meet requirements stated in Table 2-9. The planimetric (horizontal) accuracy of USACE orthophotos shall meet the ALimiting RMSE in X and Y@ stated in Table 2-2 for Classes 1 through 3. Acceptable "Photo Negative Scales" for Classes 1 through 3 will correspond with those indicated in Table 2-7. The pixel size in the image must be appropriate for showing the necessary ground details at the desired plot scale. Table 2-10 summarizes recommended pixel sizes for final map scales of digital orthophotographs. Orthophotos shall depict all visible image features in the correct planimetric position to the accuracy specified in subparagraph *c* below. Image displacements caused by ground relief and tilt shall be removed. Image displacement resulting from height of structures is inherent in typical orthophoto production processes and may not be removed without significant additional effort and time. When requested as an orthophoto overlay, topographic line and point data shall meet the topographic map standards previously set forth in this chapter.

Table 2-9
Digital Orthophoto Enlargement Factor From Photo Negative Scale

Class	Enlargement
1	4X TO 6X
2	7X TO 8X
3	9X TO 10X

c. Orthophoto accuracy statement. Specifications for USACE orthophotos shall state the accuracy in terms of ASPRS Standards for planimetric accuracy. Specifications shall also state the acceptable flight height and ground pixel resolution according to Tables 2-7 and 2-10.

Example

Aerial photography for orthophoto maps shall be flown at a photo negative scale of _____. Orthophoto maps shall meet or exceed the horizontal accuracy for ASPRS Class __ maps at 1:1,200 scale with a ground pixel resolution of _____ .

d. Compliance statement. Orthophoto maps in compliance with the USACE Standards shall include the following statement:

THIS ORTHOPHOTO MAP COMPLIES WITH ASPRS Class ____ Standards for 1:________ map scale with a Ground Pixel Resolution of ___________.

(1) The compliance statement shall refer to the data of lowest accuracy depicted on the orthophoto.

(2) Digital orthophoto maps with errors exceeding those aforestated shall omit from their legends all mention of standard accuracy.

e. Scan lines. The final orthophoto (map) shall not contain scan lines and mismatched imagery that interfere with the interpretability of ground features or the intended use of the images as specified.

2-8. Photogrammetric Mapping Coverage

Table 2-11 depicts various aerial photo mapping parameters that may be used for mission planning purposes. For more information regarding mission planning and cost estimation see Chapter 4. The Government should consider the expertise of the Contractor when planning a project. Some projects may be more economically

Table 2-10
Recommended Approximate Pixel Sizes for Selected Digital Orthophotograph Map Plot Scales

Final Map Plot Scale	Approximate Ground Pixel Resolution Required to meet USACE Accuracy Standards
1:500	0.0625 m
1"= 50 ft	0.25 ft
1:1,000	0.125 m
1"= 100 ft	0.5 ft
1:1,500	0.250 m
1:2,000	0.375 m
1"= 200 ft	1.0 ft
1:2500	0.5 m
1"= 400 ft	2.0 ft
1"= 500 ft	2.5 ft
1”= 1,000 ft	5.0 ft
1"= 2,000 ft	10.0 ft

Table 2-11
Standard Photogrammetric Mapping Coverage Parameters

Photo	9- by 9-in. Full Photo Width in feet	9- by 9-in. Full Photo Coverage Acres	Flight Line Spacing, ft	Lineal Gain Per Exposure, ft	Net Model Gain Acres
300	2,700	167	1,890	1,080	46
400	3,600	297	2,520	1,440	83
500	4,500	465	3,150	1,800	130
600	5,400	669	3,780	2,160	187
1,000	9,000	1,860	6,300	3,600	520
1,200	10,800	2,678	7,560	4,320	750
1,667	15,000	5,165	10,500	6,000	1,446
2,000	18,000	7,438	12,600	7,200	2,082.00

Notes:
1. Coverage parameters based on standard 6-in. camera, 9- by 9-in. negative size, 60 percent end lap, and 30 percent side lap. Net Model Gain = 28 percent (i.e., 0.4 by 0.7) of full photo coverage.
2. 1 acre = 43,560 square feet (sq ft)
3. 1 square mile (or section) = 640 acres

produced with deviation from the recommendations provided in Tables 2-4 through 2-11without sacrificing accuracy.

2-9. Mandatory Requirements in Chapter 2.

Mandatory requirements in Chapter 2 include paragraphs 2-3, 2-4, 2-6*d*, and 2-6*g*, and Table 2-8.