CHAPTER 1

Introduction

1-1. Purpose. This manual provides procedural guidance, accuracy standards, technical specifications, and quality control (QC) criteria for performing photogrammetric and Light Detection and Ranging (LiDAR) mapping. It distinguishes aerial and satellite based photogrammetry and LiDAR from their terrestrial and mobile counterparts; qualifies the use of these terms to be solely applicable to aerial and satellite based methods; and references the appropriate manuals in which additional relevant information can be found. Rapid changes in technology and methodologies will cause some language in this document to become outdated; therefore, this manual provides guidelines to be followed, where applicable, instead of an absolute set of requirements requiring a waiver from HQ USACE to do something outside the language contained herein.

1-2. Applicability. This manual applies to all major subordinate commands, districts, laboratories and centers performing and/or contracting for aerial and satellite data acquisition, digital orthophotography, photogrammetric and/or LiDAR mapping services in support of planning, engineering and design, construction, operations and maintenance, and/or regulation of civil works or military construction projects. This manual is also applicable to US Army Corps of Engineers (USACE) functional areas having responsibility for environmental investigations and studies, archeological investigations, historical preservation studies, hazardous and toxic waste site restoration, structural deformation monitoring investigations, regulatory enforcement activities, and support to Army installation maintenance and repair programs and installation master planning functions. Waivers from applicability should be requested by written memorandum to Headquarters, USACE (ATTN: CECW-CE).

1-3. Distribution. Approved for public release, distribution is unlimited.

1-4. References. Required and related publications are listed in Appendix A.

1-5. Mandatory Requirements. The purpose of mandatory requirements is to assure that geospatial data developed from photogrammetric and LiDAR methods meet spatial data standards and corporate direction for geospatial data collection. The verbs “must” and “shall” are used herein to express mandatory requirements that must be complied with unless a valid waiver is obtained. The verb “should” expresses recommended actions for which some flexibility is authorized.

1-6. Scope. This manual provides standard procedures, minimum accuracy requirements, product delivery requirements and QC criteria for digital orthophotography, photogrammetric and LiDAR mapping. This includes aerial and satellite photography, topographic and

bathymetric LiDAR, topographic and planimetric mapping, including digital geospatial data for use in computer-aided design and drafting (CADD) and Geographic Information Systems (GIS).

a. Intended Use. This manual is intended to be the primary reference for contracted photogrammetric and LiDAR mapping services in support of USACE requirements. It shall be used as a guide in developing contract specifications and deliverables, preparing cost estimates, evaluating contractor proposals, and QA/QC of aerial data acquisition and photogrammetric and LiDAR mapping deliverables. It may also be used as a tutorial on geospatial technologies and accuracy standards, and as general guidance in executing some phases of geospatial data development with USACE hired-labor forces.

b. Map Scales. Although map scales are not relevant to digital orthophotos and digital elevation datasets, scale is still relevant to many planimetric and topographic maps. This manual is primarily intended to cover those large-scale [i.e., 1:4,800 (1 inch = 400 feet) or better] mapping products that support typical USACE construction projects to include detailed site plan feature mapping or topographic mapping; however, this manual also supports smaller-scale mapping up to 1:24,000-scale (1 inch = 2,000 feet) that support master planning of installations, cantonment areas, firing ranges, golf courses; forest management; environmental mapping and assessments; land cover maps; or floodplain mapping, for example, over larger areas.

c. CADD vs. GIS. The decision regarding final formats (CADD vs. GIS) of spatial data is not always clear cut. Organization, storage, manipulation and updating data in a CADD system is efficient and appropriate for many engineering and mapping purposes. Many engineering, planning, and environmental projects can make use of and may require GIS capability in spatial data analyses. CADD deliverables provide the primary benefit of having spatial content readily available and compatible with engineering design applications used throughout the Corps. The decision to move from CADD to GIS is the requirement or desire to spatially analyze the data with respect to other geospatial data of various formats, units, or types. Consistent with the SDSFIE 3.1 Gold standard, collection of the spatial data in both CADD and GIS will provide the most utility of the spatial data sets and should be the first recommendation, albeit at increased costs.

1-7. Standards. Geospatial standards promote good government by: (1) enhancing data sharing and interoperability among Federal, State and local agencies, the private sector and academia, which in turn (2) minimizes redundant data production for similar but slightly different geospatial datasets; (3) promotes cost-sharing among multiple agencies; (4) minimizes costs and maximizes benefits for geospatial data that satisfies multiple requirements; (5) promotes public access to geospatial data of benefit to all; (6) simplifies metadata and training while minimizing software variations otherwise required to support data produced to different standards; and (7) promotes consistent decision-making by everyone using the same data produced to the same

standards and acceptance criteria. Although many additional standards are listed in Appendix A, the following four standards are especially relevant to photogrammetric and LiDAR mapping.

a. Spatial Data Standards for Facilities, Infrastructure and Environment (SDSFIE). The latest approved version of the SDSFIE (see http://www.sdsfieonline.org/) is the USACE data content standard and USACE geodatabases shall be developed using this standard. Data content standards define and organize the data captured in a geodatabase, providing a list of "real-world" objects (e.g., roads, buildings, trees) for a given area of interest, their semantic definitions, and a logical data model to organize and encode "instances" of geospatial phenomena in a geospatial database (geodatabase). Mapping features that USACE traditionally collects to the SDSFIE are included in Appendix B.

b. ASPRS Positional Accuracy Standards for Digital Geospatial Data (ASPRS 2014). These ASPRS standards (see Appendix C) have replaced the ASPRS Accuracy Standards for Large-Scale Maps (ASPRS, 1990) and the ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data (ASPRS, 2004). Whereas ASPRS, 1990 and ASPRS, 2014 both utilize Class 1 as standard high accuracy products, ASPRS, 2014 provides flexible standards based totally on Root Mean Square Error (RMSE) criteria for digital orthoimagery, digital planimetric data, and digital elevation data.

c. FGDC Geospatial Positioning Accuracy Standards, Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management. Published by the Federal Geographic Data Committee (FGDC), these standards shall also be considered USACE accuracy standards, especially for geospatial data produced from ground surveys and for determination of recommended geospatial data accuracies and tolerances for a large variety of engineering, construction and facility management projects.

d. Content Standard for Digital Geospatial Metadata (CSDGM). Geospatial metadata provides descriptive information in a standard format about geospatial datasets. Metadata describes the content, quality, fitness for use, access instructions, and other characteristics about the geospatial data. Geospatial metadata increases the longevity of geospatial data by maximizing its use. All USACE photogrammetric and LiDAR mapping projects shall include metadata fully compliant with FGDC-endorsed metadata standards.

1-8. Specifications. Geospatial specifications normally pertain to data intended for a specific application, whereas standards pertain to all applications. Specifications clearly document requirements for standard geospatial deliverables and are the basis for determining whether the contractor has met the requirements of a contract or task order. Well-developed specifications based on project requirements are key factors for ensuring that the received deliverables will be useful for their intended purposes.

1-9. Due Diligence. Prior to contracting for photogrammetric or LiDAR services, USACE shall ensure that existing data (to include aerial photography and elevation data) do not already exist that would meet project requirements. The following resources for geospatial data must be checked prior to contracting for new photogrammetric or LiDAR services:

a. USGS National Map Viewer. At http://viewer.nationalmap.gov/viewer/, the U.S. Geological Survey's National Geospatial Program has a National Map Viewer and download interface for up-to-date geospatial base data. Base data layers include: US Topo availability, Geographic Names Information System (GNIS), Structures, Transportation, Governmental Unit Boundaries, Map Indices, National Hydrography Dataset (NHD), Land Cover, National Elevation Dataset (NED), Elevation Contours, Imagery, and Reference Polygons. Natural hazards and other datasets are available including USGS Ecosystems, USGS Protected Area Owner, USGS Protected Area Conservation Status, USGS GAP Land Cover, FWS Wetlands, BLM Public Land Survey System (PLSS), National Park Service Boundaries, and NGA U.S. National Grid.

b. USGS Earth Explorer. At http://earthexplorer.usgs.gov/, Earth Explorer, provided by the U.S. Department of the Interior (DOI), is a platform for downloading aerial and satellite imagery as well as other geospatial datasets available for download: Aerial Imagery, Advanced Very High Resolution Radiometer (AVHRR), Calibration/Validation (Cal/Val) Reference Sites, Commercial, Declassified Data, Digital Elevation Models (DEMs), Digital Line Graphs (DLGs), Digital Raster Graphics (DRGs), Forest Carbon Sites, Earth Observing-1 (EO-1), Global Fiducials, Global Land Survey, Heat Capacity Mapping Mission (HCMM), Joint Experiment of Crop Assessment and Monitoring (JECAM), Land Cover, Landsat Archive, Landsat Calibrated Data Record (CDR), Landsat Legacy, Landsat Multi-Resolution Land Cover (MRLC), LiDAR, NASA Land Processes Distributed Active Archive Center (LPDAAC) Collections (including AirMOSS, ASTER and MODIS), Orbview-3, Radar (SIR-C), and Vegetation Monitoring.

c. National Agriculture Imagery Program (NAIP). At http://datagateway.nrcs.usda.gov/, the geospatial data gateway, sponsored by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), provides a source for environmental and natural resource data for the U.S. Imagery is mostly at statewide extent, acquired yearly and at resolutions of 1-2 meter natural color and color infrared. The following datasets are available for download: Cadastral, Census, Climate Precipitation, Climate Prism Raster, Climate Temperature, Common Land Units, Disaster Events, Easements, Elevation, Elevation Derivatives (Slope, Aspect and Hillshades), Geographic Names, Geology, Government Units, Hydrography, Landmarks, Land Use Land Cover, Map Indexes, Ortho Imagery, Soils, Topographic Images, and Transportation.

d. Geo Community. At http://data.geocomm.com, the GIS Data Depot is an online resource for GIS and geospatial data. Statewide and County data can be downloaded including the

following datasets: National Elevation Dataset (NED), National Wetland Inventory (NWI), Digital Line Graph (DLG), Digital Raster Graphic (DRG), Land Use/Land Cover (LU/LC), National Hydrography Dataset (NHD), Digital Orthophoto Quarter Quads (DOQQ), FEMA Q3 Flood Data, Census/TIGER files, Geographic Names Information System (GNIS), Place Name Gazetteer, etc.

e. FGDC Geospatial Platform. At http://www.geoplatform.gov/, the Geospatial Platform collects data from various government and private sources. Its sole purpose is to expand access to high quality data for anyone to use. Currently, there are over 63,000 datasets available including imagery, depending on the location and the date requested.

f. Digital Coast. At https://www.csc.noaa.gov/digitalcoast, the NOAA Coastal Services Center (CSC) provides coastal intelligence needed to conserve natural resources and make coastal communities more resilient. Coastal LiDAR, Coastal Change Analysis Program (C-CAP), National Ocean Watch, Electronic Navigation Charts (ENCs) and emergency response imagery, for example, are vital for addressing coastal issues such as sea level rise, coastal storms, natural resources, natural disasters, and long range planning.

g. U.S. Interagency Elevation Inventory. At http://www.csc.noaa.gov/inventory/, the inventory displays high-accuracy topographic and bathymetric data for the United States and its territories. The project is a collaborative effort between NOAA and USGS, with contributions from FEMA. This resource is a comprehensive, nationwide listing of known high-accuracy topographic data, including LiDAR and IFSAR, and bathymetric data, including NOAA hydrographic surveys, multibeam data, and bathymetric LiDAR. This inventory is updated annually. The information provided for each elevation dataset includes many attributes such as vertical accuracy, point spacing, and date of collection. A direct link to access the data, or information about the contact organization, is also available through the inventory.

h. Open Topography. At http://www.opentopography.org/, the National Science Foundation's Open Topography portal offers publicly available high resolution topography data. The topography data are acquired by LiDAR sensors and downloadable in many forms. Data types include: Point Cloud and Custom DEMs, Raster, Google Earth Files, and Metadata. Open topography also has a registry of downloadable tools specifically designed for high resolution topography data.

i. Geodata.gov. At http://geo.data.gov, the GeoData.gov portal provides the largest web-based access at a single point for maps, government data, and geospatial services.

j. GRiD. At https://rsgis.crrel.usace.army.mil/gridace, the Geospatial Repository and Data Management System (GRiD) is designed to make LiDAR, imagery and other types of geospatial data more accessible to the end user. GRiD's principal features are 1) the use of geospatial

database technology at the lowest level of data storage, 2) web access to the database for both human end-users and automated systems, 3) server-side processing to derive new geospatial products, and 4) flexibility with respect to data formats. Instead of flat-file storage, GRiD saves in its database both the data and metadata together at the level of the individual data point. This allows for efficient retrieval of specific data from a user-defined are of interest (AOI). The database also enables simple location-aware filtering of the sometimes multiple datasets found within an AOI. In addition, GRiD has integrated data compression into the production flow and enabled use of compressed files to efficiently store LiDAR data on a local workstation. For more information about GRiD use across USACE please contact: David C. Finnegan, Cold Regions Research & Engineering Laboratory, Hanover, NH 03755, (603) 646-4106, david.finnegan@usace.army.mil.

1-10. Metrics. Both metric (System International or simply SI) and English systems of measurement are used in this manual due to the common use of both systems throughout USACE. Whereas the ASPRS Positional Accuracy Standards for Digital Geospatial Data (ASPRS 2014) in Appendix C are in metric units, Chapter 3 provides the primary ASPRS tables in both metric and English units.

a. Metric Scale Ratios. Metric scale ratios are generally required for civil works or military construction. Both English and metric scales are expressed. English scales are generally expressed as “1 in. = x ft” notation, or more commonly, “x ft/in.” Unit ratio (i.e., 1:x) scale measures may also be used for English units and are used throughout this manual for metric units. For example, a 100-scale map represents a 100-ft/in.-scale map, or 1 in. = 100 ft, or 1:1,200. However, when creating a map in metric units the map scales are generally in multiples of 1, 2 or 5 (e.g., 1:500, 1:1,000 or 1:20,000). Direct conversion from English units to metric units (e.g., 1’ = 100’ to 1:1,200) should not be a common map scale for a mapping project intended to be metric in scale. The map scale should be the nearest common metric map scale (e.g., converting to metric for an English map scale of 1”=100’ should be 1:1,000 rather than 1:1,200). Exceptions can be made when a different map scale is required, e.g., 1:25,000.

b. English Scale Ratios. English scales follow similar rules whereby 1” = x’ normally expresses “x” in multiples of 1, 2 or 5 feet (e.g., 1”=50’, 1”=200’ and 1”=1000’) for which these examples are the same as 1:600, 1:2,400 and 1:12,000 – inappropriate for metric scales. Again, an exception can be made when a different map scale is required, e.g., 1”=75’, rather than either 1”=50’ or 1”=100’.

c. Metric Conversions. In all cases, metric conversions are based exclusively on the US Survey Foot which equals exactly 12/39.37 meters.

1-11. Using this Manual. Photogrammetry and LiDAR are professional specialties closely linked to digital technologies that are rapidly changing and for which accuracy and quality standards are also rapidly changing. Gone are the days when specified map scales or contour

intervals dictated image scales and flying heights; continuous improvements in optics and LiDAR pulse repetition rates cause flying heights appropriate for a digital sensor to be obsolete when older sensors are upgraded. The capabilities of digital cameras, LiDAR sensors and production software are improving so rapidly that prior criteria are meaningless. Many mapping tasks, previously performed manually, are now performed automatically or semi-automatically. Whereas this is intended to reduce the cost and duration of mapping projects, this may signal the need for increased quality assurance/quality control (QA/QC) to ensure that the government receives the quality products expected. Although there are four chapters devoted to technical procedures, it is not the intent of this manual to educate the reader to the proficiency level of a photogrammetric or LiDAR technician. Instead, this manual is intended to present procedural guidance, technical specifications, accuracy standards and quality control (QC) criteria for performing photogrammetric and LiDAR mapping.

a. Chapter 2, Photogrammetry and Metric Remote Sensing. This chapter provides an introduction to aerial and satellite photogrammetry and other metric remote sensing technologies, including LiDAR and IFSAR (Interferometric Synthetic Aperture Radar), which USACE might use for creation of geospatial information. This chapter primarily serves to compare the products from various technologies and to summarize their respective advantages and disadvantages.

b. Chapter 3, Applications and Accuracy Standards. This chapter explains and supplements Appendix C, the new ASPRS Positional Accuracy Standards for Digital Geospatial Data (ASPRS, 2014) adopted by USACE. Chapter 3 provides key tables in English units that are depicted only in metric units by ASPRS; and it includes an updated table of recommended surveying and mapping specifications for various USACE applications. The primary goal of this chapter is to define accuracy standards specific to the Corps' needs for geospatial products and services. This requires a modern review, as accuracy criteria are not static, of the Corps' use of geospatial content and a determination of minimum accuracy requirements for each uniquely identified use or product. Once determined, any Corps-specific product and associated accuracy standard(s) could be related, if necessary, to the latest ASPRS industry-wide accuracy standards.

c. Chapter 4, Aerial Photogrammetry. This chapter summarizes definitions and applications of digital photogrammetry; provides project specifications for digital orthophotos, planimetric mapping and topographic mapping; and provides guidance for planning of photogrammetric projects to include aircraft, sensors, aerial data acquisition, ground control, aerial triangulation, orthophoto production, photogrammetric mapping, quality control, and factors impacting costs.

d. Chapter 5, Satellite Photogrammetry. This chapter provides an overview of satellite photogrammetry and compares high- and medium-resolution commercial imaging satellites for use in orthophoto mapping, planimetric mapping, classification mapping, and topographic mapping. It explains geo-positioning of satellite images and creation of satellite imagery stereo pairs. It concludes with "Ten Things to Consider in Buying Optical Satellite Imagery" to include

spatial resolution, spatial accuracy, off-nadir angle/elevation angle, sun elevation, spectral information, projection, resampling method, collection capacity, cloud cover, and delivery method.

e. Chapter 6, Airborne Topographic LiDAR. This chapter provides a technology overview of airborne topographic LiDAR systems and enabling technologies; considerations in development of LiDAR project specifications; LiDAR project planning to include survey control and quality control checkpoints; LiDAR data processing, LAS classification, hydro flattening; development of LiDAR products including breaklines and metadata; LiDAR deliverables; and quality assurance.

f. Chapter 7, Airborne Bathymetric LiDAR. This chapter provides a technology overview of airborne bathymetric LiDAR systems and current sensor technologies; USACE's JALBTCX program and CZMIL sensor; project specifications; comparison of LiDAR with other technologies (imagery and acoustic surveys); acquisition requirements; processing requirements; and project planning considerations.

g. Chapter 8, Project Planning. This chapter contains general guidance for USACE project engineers, project managers, or project engineering technicians who are required to plan for photogrammetric or LiDAR mapping projects to be executed under negotiated qualification-based Architect-Engineer (A-E) contracts.

h. Chapter 9, Contracting and Cost Estimating. This chapter is designed to equip government personnel to better estimate "relative" (not absolute) costs associated with procuring professional mapping services. Chapter 9 will help Contracting Officers (COs), Contracting Officer Representatives (CORs) and technical personnel associated with contracting to better estimate how the scope, schedule, and technical merits of a project can affect the relative cost of professional mapping services. This chapter will not help determine the actual costs associated with procurement of professional mapping services; but it will help readers understand which factors should be considered when drafting a solicitation and how those factors affect the associated cost, schedule, and complexity of the procurement.

i. Appendix A, References. This Appendix includes a listing of all referenced publications and other publications relevant to EM 1110-1-1000.

j. Appendix B, Planimetric and Topographic Feature Depiction Specifications. This Appendix provides USACE specifications for the capture and/or depiction of planimetric and topographic features.

k. Appendix C, ASPRS Positional Accuracy Standards for Digital Geospatial Data. This Appendix lists, verbatim, the *ASPRS Positional Accuracy Standards for Digital Geospatial Data* (ASPRS, 2014). It includes four ASPRS annexes [A – Background; B – Data Accuracy and

Quality Examples; C – Accuracy Testing and Reporting Guidelines; and D – Accuracy Statistics and Examples.]

l. Appendix D, Guide Specification for Photogrammetric Mapping and Aerial Photography Services.

m. Appendix E, USGS Lidar Base Specification Version 1.1 (Heidemann, 2014).

n. Appendix F, Example Scope of Work for Digital Orthophotography and Planimetric Feature Collection, and Cost Estimate Form.

o. Appendix G, Example Scope of Work for Aerial LiDAR and Digital Orthophotography Data Collection, and Cost Estimate Form.

p. Appendix H, Example Scope of Work for Hyperspectral Image Acquisition for Delineating Permafrost and Ground State Conditions, and Cost Estimate Form.

q. Appendix I, Example Scope of Work for JALBTCX Project, and Cost Estimate Form.

1-12. Trade Names. The citation in this manual of trade names of commercial firms, commercially available mapping products, hardware or software, does not constitute their official endorsement or approval.

1-13. Manual Development and Proponency. The proponent for this manual is HQUSACE Directorate of Civil Works Engineering and Construction Division (CECW-CE). Technical development and compilation of the manual was coordinated by the USACE Photogrammetric Mapping Center of Expertise at St. Louis District. Comments or recommended changes to this manual should be forwarded to HQUSACE (ATTN: CECW-CE).

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