CHAPTER 1

Introduction

1-1. Purpose. This manual provides technical specifications and procedural guidance for surveying and mapping with the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS). It is intended for use by planning, engineering, operations, real estate, and construction personnel performing georeferenced feature mapping or geodetic control surveys for all US Army Corps of Engineers (USACE) projects to include civil works and military construction. Procedural and quality control standards are defined to establish Corps-wide uniformity in the use of GPS by hired-labor personnel, construction contractors, and Architect-Engineer (A-E) contractors.

1-2. Applicability. This manual applies to all USACE commands having responsibility for the planning, engineering and design, construction, operation, maintenance, and related real estate and regulatory functions of civil works, military construction, and environmental restoration projects. It applies to GPS survey performance by both hired-labor forces and contracted survey forces. It is also applicable to surveys performed or procured by local interest groups under various cooperative or cost-sharing agreements.

1-3. Distribution. This publication is approved for public release; distribution is unlimited.

1-4. References. Referenced USACE publications and related bibliographic information are listed in Appendix A. Where applicable, primary source material for individual chapters may also be noted within that chapter. Up to date information on GPS systems, processes, equipment, and vendors may be obtained through the Army Geospatial Center's GPS web site: http://www.agc.army.mil/ndsp. As technology advances, the referenced documents may be revised and, as such, those referenced here may not be the most current.

1-5. Background. GPS was developed by the U.S. Department of Defense (DoD). It is now only one of a growing number of Global Navigation Satellite Systems (all of which provide global, all-weather, 24-hour-a-day positioning services based on timing and ranging of radio signals transmitted from constellations of orbiting satellites). GPS remains the most robust and reliable and is the focus of this manual. GPS surveying is a process by which highly accurate, three-dimensional point positions are determined from signals received from satellites. GPS-derived positions may be used to provide the primary reference control monument locations for engineering and construction projects, from which detailed site plan topographic mapping, boundary demarcation, and construction alignment work may be performed using conventional surveying instruments and procedures. GPS surveying also has application in the precise positioning of marine floating plant and photogrammetric mapping aircraft, and in monitoring structural deformations of locks and dams. GPS surveying techniques are also used for the rapid, real-time geospatial feature mapping of wetlands, facilities, utilities, and related Geographic Information System (GIS) products. USACE commands first began using GPS in 1983, primarily for establishing precise positions on fixed monuments to control navigation and military construction projects. In the early 1990s, commands began using kinematic GPS for real-time control of hydrographic survey vessels and dredges, and real-time topographic mapping. In the later 1990s, GPS applications expanded to precise airborne positioning for

photogrammetric mapping and Light Detection and Ranging (LiDAR) terrain modeling applications. Simple operated hand-held GPS receivers using the Wide-Area Augmentation System (WAAS) in North America and the European Geostationary Navigation Overlay Service (EGNOS) throughout Europe are capable of delivering more accurate (to within a few meters in all three dimensions), real-time geospatial coordinates and feature data for an expanding and unlimited number of USACE positioning and navigation applications.

1-6. Use of Manual. This manual is intended to be a USACE reference guide for a variety of GPS applications, including: precise control surveying, topographic site plan mapping, GIS feature mapping, positioning, and navigation. These activities may be performed by hired-labor forces, contracted forces, or combinations thereof. It is also used as the primary reference manual for Proponent Sponsored Engineer Corps Training (PROSPECT) courses on GPS surveying. General planning criteria, field and office execution procedures, and required accuracy specifications for performing GPS surveys in support of USACE engineering, construction, operations, planning, and real estate activities are provided. Accuracy specifications, procedural criteria, and quality control requirements contained in this manual shall be directly referenced in the scopes of work for A-E survey services or other third-party survey services. This is intended to assure that uniform and standardized procedures are followed by both hired-labor and contract service sources throughout USACE. Throughout the manual, recommended GPS surveying and mapping criteria are normally summarized in tables. Technical or procedural guidance is in more general terms where methodologies are described in readily available references or in GPS instrumentation and software operating manuals. Where procedural guidance is otherwise unavailable from industry sources, it is provided herein.

1-7. Scope of Manual. The original version of this manual was developed in the late 1980s and published on 14 June 1991 by the USACE Engineer Topographic Laboratory at Fort Belvoir (now the Army Geospatial Center). The 1991 version was subsequently revised on 31 December 1994 and 1 August 1996. These original versions contained detailed GPS theory, operational instructions, procedures, and equipment procurement guidance, and were based on the technology and observational methods that were still evolving during that period. Since GPS theory and observational methods are now covered in various DoD technical documents, academic publications, and/or GPS equipment manufacturer's manuals, the current update is more focused on specific USACE project applications, accuracy standards, observation criteria, and adjustment analysis.

a. General coverage. This update to the manual primarily focuses on the use of static and kinematic differential carrier phase GPS survey techniques for establishing and/or extending project horizontal and vertical construction control, boundary control, and topographic site plan mapping. Both static and kinematic control survey methods are covered, along with related GPS data reduction, post-processing, and adjustment methods. Absolute GPS point positioning methods (i.e. non-differential) and code-phase differential navigation positioning from wide-area augmentation networks are covered to a lesser extent since these techniques are not normally employed for establishing high-accuracy control coordinates on project reference monuments. These techniques do, however, have an expanding application on many USACE surveying and GIS feature mapping projects. Dynamic differential code/carrier-phase GPS positioning methods supporting hydrographic surveying and dredge control are also covered in EM 1110-2-

1003 (Hydrographic Surveying). Airborne mapping and LiDAR applications of GPS are covered more fully in EM 1110-1-1000 (Photogrammetric Mapping). High-precision uses of GPS for monitoring structural deformations are more thoroughly described in EM 1110-2-1009 (Structural Deformation Surveying). Additional guidance on the use of GPS for making project connections to the National Spatial Reference System may be found in EM 1110-2-6056, *Standards and Procedures for Referencing Project Elevation Grades to Nationwide Vertical Datums*.

b. Manual coverage and appendices. The first few chapters in this manual are intended to provide a general overview of the theory and physical concepts of satellite GPS positioning, including coordinate systems and reference datums. Subsequent chapters cover GPS survey planning, data acquisition, data processing, and data adjustment and analysis. The final chapter on estimating costs for GPS surveys is intended to assist those USACE commands that contract out these services. The appendices to this manual contain detailed examples of GPS surveys covering a variety of Corps projects--both civil and military that have been conducted over the last two decades. Users should be aware that these sample applications are representative of and consistent with the equipment, field and office processing methods, and coordinate reference systems in use at the time of the surveys. Samples that are not current have been retained in this manual as examples of thorough and proper documentation, good general field acquisition and processing philosophy, and because of their exposition of those surveying, processing and adjustment fundamentals that do not change substantially over time. However, it should be understood that the technology is advancing, techniques are changing, achievable accuracies are improving, and the breadth of applications is expanding. Therefore, users should always look primarily to relevant examples of the most current and up to date GPS applications and accuracies. For further information on GPS, and to stay abreast of this continuously changing technology, users of this manual should periodically consult the related publications, governmental agencies, and the Internet web site listed in paragraph 1-4 above.

c. Evolving GPS technology and procedures. Equipment operation, calibration, and procedural methods for acquiring, logging, processing, and adjusting GPS survey data are usually adequately detailed in operation manuals provided by the various GPS equipment manufacturers and geodetic adjustment software vendors. Since many of the receiver operation and data processing methods are unique to each vendor, and are being constantly updated, this manual can only provide a general overview of some of the more common techniques used by USACE or its contractors. References and recommendations in this manual of any specific operational or adjustment methods must be carefully weighed against newly evolving technology and the latest manufacturer's recommendations. Other Corps regulations may dictate mandatory requirements for processing, displaying, transferring, and archiving GPS survey data--e.g., Metadata archiving. These mandatory regulations will be referenced where applicable. As new GPS survey instruments, technology, and procedures are developed, Districts are strongly encouraged to use those innovations and recommend modifications to any criteria or technical guidance contained in this manual--see Proponency and Waivers section at the end of this chapter.

1-8. Life Cycle Project Management Applicability. Project control established and periodically checked and verified by GPS survey methods may be used through the entire life cycle of a

project, which may sometimes span decades. During initial reconnaissance surveys of a project, control established by GPS should be permanently monumented and situated in areas that are conducive to the performance or densification of subsequent surveys for contract plans and specifications, construction, and maintenance. During the early planning phases of a project, a comprehensive survey control plan should be developed which considers survey requirements over a project's life cycle, with a goal of eliminating duplicative or redundant surveys to the maximum extent possible.

1-9. Metrics and Accuracy Definitions. Metric units are used in this manual. Metric units are commonly used in geodetic surveying applications, including the GPS survey work covered in this manual. GPS-derived geographical or metric Cartesian coordinates are generally transformed to English units of measurements for use in local project reference and design systems, such as State Plane Coordinate System (SPCS) grids. In all cases, the use of metric units shall follow local engineering and construction practices. English/metric equivalencies are noted where applicable, including the critical--and often statutory--distinction between the US Survey Foot (1,200/3,937 meters (m) exactly) and International Foot (30.48/100 m exactly) conversions. One-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D) accuracy statistics, standards, and tolerances specified in this manual are defined at the 95% RMS confidence level. Unless otherwise stated, GPS "positional accuracies" imply horizontal (2-D) RMS measures. The generic term "meter-level GPS" generally refers to 2-D accuracies ranging between 0.5 m and 5 m. Likewise, "centimeter-level GPS" typically refers to 1-D, 2-D, or 3-D GPS accuracies ranging between 1 cm and 10 cm.

1-10. Trade Name Exclusions. The citation or illustration in this manual of trade names of commercially available GPS products, including other auxiliary surveying equipment, instrumentation, and adjustment software, does not constitute official endorsement or approval of the use of such products.

1-11. Abbreviations and Terms. Abbreviations and acronyms are listed at Appendix B. GPS surveying terms used in this manual are explained in the Glossary at the end of this manual.

1-12. Mandatory Requirements. ER 1110-2-1150 (Engineering and Design for Civil Works Projects) prescribes that mandatory requirements be identified in engineer manuals. Mandatory accuracy standards, quality control, and quality assurance criteria are normally summarized in tables within each chapter, and these requirements are summarized at the end of the chapter. If no mandatory requirements are listed, then the material in a particular chapter is considered recommended guidance. The mandatory criteria contained in this manual are based on the following considerations: (1) project safety assurance, (2) overall project function, (3) previous Corps experience and practice, (4) Corps-wide geospatial data standardization requirements, (5) adverse economic impacts if criteria are not followed, and (6) HQUSACE commitments to industry standards.

1-13. Governing Engineer Regulations and Related Standards. Spatial coordinates established using GPS techniques fall under the definition of geospatial data contained in ER 1110-1-8156 (Policies, Guidance, and Requirements for Geospatial Data and Systems). Accordingly, the guidance in ER 1110-1-8156, and its implementing manual EM 1110-1-2909 (Geospatial Data

and Systems) as well as the regulations in ER 1110-2-8160 (Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums) and its implementing manual EM 1110-2-6056 (Standards and Procedures for referencing Project Elevations Grades to Nationwide Vertical Datums), must be followed for disseminating and archiving GPS-derived data. This would include preparing appropriate metadata files in accordance with the guidance in EM 1110-1-2909. Federal standards for reporting survey accuracy, geodetic control survey standards, and topographic survey standards are published by the Federal Geographic Data Committee (FGDC). These FGDC "Geospatial Positioning Accuracy Standards" are listed in Appendix A. USACE commands shall comply with these FGDC standards. This manual also references a number of Corps technical manuals listed in Appendix A. These referenced manuals contain guidance relating to performing GPS surveys for more specific applications.

1-14. Proponency and Waivers. The Headquarters, USACE (HQUSACE) proponent for this manual is the Engineering and Construction Division, Directorate of Civil Works. Technical development and compilation of the manual was coordinated by the Army Geospatial Center. Comments, recommended changes, or waivers to this manual should be forwarded through MSC to HQUSACE (ATTN: CECW-CE).