AN INTERVIEW DR. DAVID F. MAUNE



DEM Users Manual 3rd Edition A Preview

Chapter 1—Introduction to Digital Elevation Models, along with Appendix A (Acronyms) and Appendix B (Definitions), establishes the DEM vocabulary and definitions for various forms of elevation raster data, vector data, and point data (including point clouds) so that data users and producers can agree on standardized terminology. It is important that DEM users understand the concepts of mass points. breaklines, and triangulated irregular networks (TINs), for example, and how they are used to produce uniformly spaced topographic and/or bathymetric DEMs. This chapter also covers topographic and hydrologic surface modeling, e.g., hydro-flattening, hydro-enforcement and hydro-conditioning with examples at Figures 1 through 6 (below), as well as elevation derivatives and 3D terrain visualization. Definitions from this manual were also incorporated in the USGS Lidar Base Specification.



Chapter 2—Vertical Datums defines a vertical datum as a reference surface representing zero height – whether heights above sea level (with various tidal datums), orthometric heights (elevations) above the geoid with equal gravity potential (with various vertical orthometric datums), or ellipsoid heights above a mathematical ellipsoid that approximates the shape of the Earth as obtained from air-, land- or sea-based GPS. It is important that DEM users understand geoid undulations, how all U.S. vertical datums of the future will be geoid based vertical datums that result from the National Geodetic Survey's Gravity for the Redefinition of the American Vertical Datum GRAV-D) project, and how to transform from one vertical



Dr. David F. Maune served 30 years of Army active duty as a commissioned officer in the U.S. Army Corps of Engineers (USACE). He specialized as a Topographic Engineer, last serving as Commander and Director, U.S. Army Topographic Engineering Center (TEC) – now the Army Geospatial Center (AGC). Today He is a Senior Project Manager for Dewberry Engineers, Inc. and currently editing the 3rd edition of "Digital Elevation Model Technologies

and Applications: The DEM Users Manual."

What did you learn from your active duty years in U.S. Army Corps of Engineers (USACE)?

Nearly all engineers apply the principles of science and mathematics to develop economical solutions to technical problems; their work is the link between scientific discoveries and the commercial applications that meet societal and consumer needs. Topographic engineers apply the principles of geodesy and various forms of remote sensing to map topographic and bathymetric surfaces – also to satisfy societal and consumer needs. During my Army years, most engineers in USACE built physical infrastructure; but topographic engineers built geospatial infrastructure.

Tell us about your background that lead you to editing the DEM Users Manuel?

I retired from Army active duty in 1991 and joined Dewberry in 1992 where I initially applied my expertise to floodplain mapping for FEMA; fortunately, I was able to pioneer FEMA's evaluation of lidar and IfSAR. At the ASPRS annual conference in 2000, I published a paper entitled: "Lidar and IfSAR: Pitfalls and Opportunities for our Future." That paper was so well received that the ASPRS Executive Board asked me to write an ASPRS book on lidar and IfSAR. I replied that I would do so provided I could also include other technologies including photogrammetry, bathymetric lidar and sonar, and write it with a focus on the needs of DEM users, whether the DEM pertained to topographic or bathymetric surfaces.

The 1st edition of "Digital Elevation Model Technologies and Applications: The DEM Users Manual" was published in 2001, and the 2nd edition was published in 2007. Having almost no standard DEM products in those days, both editions included a User Requirements Menu for which users could pick and choose from a large array of choices for elevation surface types, data model types, source data, vertical and horizontal accuracy, accuracy testing and reporting, forms of hydro treatments, horizontal and vertical datums, geoid models, units, data formats, and metadata. Because technologies were immature, we had no nationwide DEM standards, guidelines and specifications, other than the FEMA guidelines that long served as a de facto lidar specification. My User Requirements Menu unknowingly demonstrated our need for standard products because all of these menu choices led to a broad assortment of nonstandard DEM products that were often incompatible with adjoining datasets.

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What motivated the new edition of the "The DEM User Manuel"?

Whenever I autograph a copy of the DEM Users Manual, I write "May all your DEMs come true!" This is an obvious play on words with "May all your dreams come true." When the 2^{nd} edition was published, I had three basic dreams:

- 1. Development of high-accuracy, affordable elevation technologies for the betterment of society
- 2. Development and update of DEM technology standards, guidelines and specifications, and
- 3. Implementation of a nationwide program, such as today's 3D Elevation Program (3DEP), to produce and maintain standardized high-quality DEMs used by all.

These first three dreams have largely been realized, as documented in this 3^{rd} edition. My future dreams include:

- 4. Development of a seamless 3D Nation from the tops of the mountains to the depths of the seas, to include inland bathymetry
- 5. Use of the latest elevation data to routinely and systematically update the National Hydrography Dataset (NHD), flood studies, forest metrics and other datasets that require up-to-date topographic and bathymetric DEMs, and
- 6. Development of DEM applications to fully support the dozens of business uses and hundreds of mission-critical activities (MCAs) documented in the National Enhanced Elevation Assessment (NEEA) study published in 2012 and the 3D Nation Requirements and Benefits Study being conducted in 2018-2019.

The focus of this 3^{rd} edition of the DEM Users Manual is to help make all of these dreams come true.

Is there recent progress in the production of digital elevation models ASPRS members should note?

Over the past decade, technologies have matured, and much progress has been made towards standardization:

- In 2010, the U.S. Geological Survey (USGS) published its draft Lidar Guidelines and Base Specifications, V.13, which ultimately became the USGS Lidar Base Specification, V1.0.
- In 2012, the NEEA study was published that provided a comprehensive analysis of DEM user requirements and benefits for five Quality Levels (QLs) of topographic DEMs.
- In 2012, USGS published its Lidar Base Specification, V1.0.
- In 2013, based on the NEEA implementation scenario with the highest return-on-investment, USGS announced the new 3DEP to deliver QL2 lidar nationwide except for QL5 IfSAR statewide in Alaska.
- In 2013, ASPRS published its latest LAS Specification, V1.4.

datum to another. Figure 7 (right) is an image from Chapter 2 that explains the difference between orthometric heights, ellipsoid heights, and geoid undulations.



Chapter 3—Standards, Guidelines and Specifications introduces DEM users to the ASPRS Positional Accuracy Standards for Digital Geospatial Data v1.0, the ASPRS LAS Specifications v1.4, the USGS Lidar Base Specifications v1.3, the National Ocean Service (NOS) Hydrographic Survey Specifications based on standards of the International Hydrographic Organization (IHO), and other relevant standards, guidelines and specifications. It is important that DEM users understand these documents and how they must be rigorously enforced to achieve our vision of a seamless, consistent, high-accuracy, high-resolution 3D Nation, from the tops of the mountains to the depths of the sea.

Chapter 4—The National Elevation Datase–NED provides the background, rationale and history of the legacy NED and how NED data were produced, quality controlled and delivered to the public. It provides information about NED specifications and production processing, accuracy and data quality. The NED was retired when the 3DEP became operational, but USGS is de-

veloping a new line of science products known as the Coastal National Elevation Database (CoNED) which integrates recent high resolution coastal lidar data (both topographic and bathymetric) and a temporal component from captures on different dates. An example of a CoNED dataset is shown at Figure 8 (right).



Chapter 5—The 3D Elevation Program–3DEP explains USGS' national elevation initiative that forms the elevation layer of The National Map. The 3DEP resulted from analyses and vetting of the NEEA study which assessed



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DEM user requirements and benefits and concluded that the highest return on investment would come from QL2 lidar nationwide except for QL5 IfSAR of Alaska. The chapter describes the 3DEP program; the U.S. Interagency Elevation Inventory (USIEI); the USGS Lidar Base Specifications; the Broad Agency Announcement (BAA) process; acquisition trends; 3DEP data quality assurance; 3DEP products, services and data dissemination; current developments and future directions. Figure 9 (previous page) shows 3DEP partnership awards for FY2018 alone, a major reason why the 3DEP is so popular and successful.

Chapter 6—Photogrammetry explains airborne and satellite digital imaging systems; project planning considerations; georeferencing and aerotriangulation; photogrammetric data collection methods (softcopy stereoplotters, manual and automated elevation collection); post processing; data deliverables; enabling technologies; calibration procedures; capabilities and limitations compared with competing/complementary technologies; DEM user applications; cost con-

siderations; and technological advancements. It is important that DEM users understand the capabilities and limitations of photogrammetry compared with lidar and IfSAR, for example. Figure 10 (right) is an example of a DEM produced with Structure from Motion (SfM) photogrammetry and UAV imagery.



Chapter 7—Interferometric Synthetic Aperture Radar–IfSAR explains how interferometric synthetic aperture radar works, airborne and satellite If-SAR alternatives, how aerial IfSAR is completing the first-ever mapping of Alaska to specified accuracy standards, and how differential IfSAR/InSAR is used to monitor subsidence at the mm level. Mapping through clouds with high-resolution Ortho-rectified Radar Images (ORIs) and able to pan-sharpen

low-resolution satellite imagery (with clouds), the IfSAR statewide mapping of Alaska will be completed in 2019, the first time that Alaska has ever been mapped to ASPRS accuracy standards. Figure 11 (right) shows the hydrographic feature detail of IfSAR data.



Chapter 8—Airborne Topographic Lidar explains the basic concepts of topographic lidar scanning and sensors; compares traditional linear-mode lidar with photon-sensitive and Geiger-mode lidar; boresight calibration; airborne lidar project planning; and the status of current lidar sensor technologies from Teledyne Optech, Leica Geosystems, Riegl, and Harris Corp. Figure 12 (right) shows a typical lidar aircraft with GPS and IMU, scanning the terrain beneath.



Chapter 9—Lidar Data Processing explains concepts and approaches to automated filtering of lidar point clouds to include ground and non-ground points, noise, vegetation, structures and other above-ground features; manual editing of lidar; breakline processing to include area and linear hydrographic features, structures, manual review and editing; elevation assignment to breakline features, to include linear and area hydrographic feature elevation assignment; DEM processing concepts and approaches, processing techniques, incorporat-

ing breaklines; DSM processing; and other derivative products including contours. Figure 13 (right) demonstrates procedures for hydro-enforcement and continuous downsteam flow (monotonicity).



Chapter 10—Airborne Lidar Bathymetry explains the basic concepts of bathymetric lidar scanning and sensors; system design; data processing including system calibration; output formats and deliverables; and the status of current sensors including SHOALS, CZMIL, LADS, Chiroptera II/Hawk Eye III, EAARL, VQ 820/880-G, and Titan; operational and planning considerations; and comparisons with overlapping technologies. Figure 14 (below) demonstrates the bathymetric surface detail of this dataset produced by Dewberry for the NOAA Office for Coastal Management.



Chapter 11—Sonar provides a technology overview and developmental history of acoustic mapping and explains the basic principles used, to include acoustic sources and directional transmit/receive transducers. It explains the different types of sonars (vertical beam, multibeam, side scan, interferometric, focusing, and Doppler); present operating status; platforms and installation; calibration procedures; planning considerations; capabilities and limitations and comparisons with complementary and competing technologies; post processing, quality control, data deliverables, cost considerations, and technology advancements. Figure 15 (below) demonstrates a sonar product used for safety of maritime navigation.



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- In 2014, ASPRS published its Positional Accuracy Standards for Digital Geospatial Data that included vertical accuracy classes.
- In 2014, USGS published its Lidar Base Specification, V1.2 with detailed specifications for QL0, QL1 and QL2 lidar, consistent with the ASPRS vertical accuracy classes.
- In 2015, USACE published a new EM 1110-1-1000, Photogrammetric and Lidar Mapping, endorsing both the ASPRS standards and the USGS Lidar Base Specification.
- In 2016, FEMA published its Guidance for Flood Risk Analysis and Mapping, Elevation Guidance, and it standardized on QL2 lidar as defined in the USGS Lidar Base

Chapter 12—Enabling Technologies explains the Global Positioning System (GPS) and other international systems that form the Global Navigation Satellite System (GNSS). It explains GNSS positioning technologies including GNSS single point positioning, differential GNSS, precise phase interferometry positioning, and precise point positioning (PPP). It explains local, regional and global differential GNSS, Continuously Operating Reference Stations (CORS), sensors and error sources. It explains inertial navigation systems (INS) and GNSS-aided inertial navigation technologies, direct georeferencing systems for airborne DEM generation, boresight calibration,

post processing, and motion sensing systems for multibeam sonar bathymetry. These technologies are vital for accurate and cost-effective photogrammetry, IfSAR, lidar and sonar mapping. Although Figure 16 (right) demonstrates camera boresighting, the mounting misalignment or boresight angles between the IMU and the lidar reference frame are similarly determined through a combination of laboratory and airborne calibration.



Chapter 13—DEM User Applications reviews how DEMs are vital for production of digital orthophotos, topographic maps and various other types of maps (soils, geologic, wetlands, forestry, wildlife habitat, cultural resources, urban and regional planning, and flood maps); underwater and coastal mapping applications (Digital Coast, sea level rise viewing, shoreline delineation, coastal management and engineering); transportation applications (land, aviation and marine navigation and safety); military applications; technical applications (hydrologic and hydraulic (H&H) modeling [Figure 17 - below], national resources onservation, water supply, subsidence, and stormwater manage-

ment; commercial applications (precision agriculture, mining, renewable energy, oil and gas, telecommunications) and individual applications. It summarized the NEEA's 27 major DEM Business Uses that helped justify the 3DEP and would be relevant also to state or local initiatives seeking funding partnerships.



Chapter 14—DEM User Requirements and Benefits explains why DEM users needing lidar data should normally state their requirements for standard QL2 lidar data consistent with the 3DEP so as to receive standard raw and classified point cloud data, standard breaklines, Specification for new lidar acquisition, consistent with the goals of the 3DEP, while also aligning with the ASPRS Positional Accuracy Standards for Digital Geospatial Data and the ASPRS LAS Specification V1.4.

- In 2017, the National Geodetic Survey (NGS) started teaming with USGS for a NEEA Update and Coastal/ Offshore Elevation Requirements and Benefits Study that might establish bathymetric equivalents to the topographic data Quality Levels in the NEEA.
- In 2018, USGS published its Lidar Base Specification, V1.3, and NOAA and USGS kicked off their 3D Nation Requirements and Benefits Study.

standard metadata, and standard hydro-flattened, bare-earth raster DEMs – all with potential common data upgrades that do not compromise standardization and interoperability. The resulting benefits include: a single authoritative source of high quality and consistent 3DEP data at lower costs for all; standard 3DEP products that use common hardware/software and standard training for data users and producers; easier generation of derivative products from a standard source – all yielding a seamless, consistent elevation surface from the top of the mountains to the depths of the sea.

Chapter 15—Quality Assessment of Elevation Data is a 90-page tutorial with images designed to promote consistency in delivery of elevation data acceptable for the 3DEP. This chapter reviews relevant standards, guidelines and specifications; explains procedures for testing and reporting absolute and relative accuracy; and goes into great detail in addressing various forms of qualitative assessments, to include: source data QA/QC; breakline QA/ QC (breakline completeness, variance and topology); macro level reviews of DEM data; and micro level reviews of topographic and topobathymetric DEMs including hydro flattening or enforcement, edge-matching, and bareearth editing of buildings, bridges and artifacts. This chapter also includes procedures for QA/QC of contours and metadata. Figure 18 (below) shows just one of the hundreds of ways in which lidar data could fail to satisfy USGS Lidar Base Specifications.



Appendix A is a list of approximately 500 acronyms used in the 3rd edition.
Appendix B provides definitions for over 500 terms used in the 3rd edition.
Appendix C explains where to download sample elevation datasets