Digital Elevation Model (DEM) Whitepaper

NRCS High Resolution Elevation Data

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Table of Contents

Purpose

The purpose of the NRCS Elevation Initiative is to execute a collaborative effort (developed by and between Soil, Inventory, Engineering and Conservation interests) to prepare NRCS business cases and data requirements for participation in the 2011 NRCS National High Resolution Elevation Acquisition and NRCS 5-year investment strategies. This will assist in developing accurate base map derivatives to assist in NRCS mapping activities. The effort to prepare NRCS business cases and data requirements for the 2011 NRCS National High Resolution Elevation Acquisition is multi-phased. The initial phase, completed in September 2008, included the development of a “NRCS Geospatial Strategy, Elevation Data 2009” which identified as a priority mid-accuracy national coverage digital elevation models (DEMs).

This DEM Whitepaper responds to a task order from the U.S. Geological Survey (USGS) Geospatial Products and Services Contract (GPSC) in support of NRCS which provided project funding. This task order addresses the second phase which includes the development of NRCS business cases and data requirements for participation in the 2011 NRCS National High Resolution Elevation Acquisition. Future phases of this initiative will be addressed in future task orders and will include analysis and planning for NRCS priority projects nationwide. NRCS requested Dewberry for execution of this task order because of the expertise of Dr. Dave Maune, Dewberry’s Senior Project Manager for Remote Sensing, who served as editor and principal author of the 1st and 2nd editions of “Digital Elevation Model Technologies and Applications: The DEM Users Manual,” published by the American Society for Photogrammetry and Remote Sensing (ASPRS) in 2001 and 2007, respectively. Appendix A of this whitepaper includes a DEM primer focused on NRCS requirements.

The referenced task order includes four essential steps:

1. Gathering elevation requirements from the NRCS user community through Survey Monkey questionnaires; NRCS regional DEM technical workshops with NRCS GIS specialists and others that serve as liaison with state soil scientists, state engineers, etc.; and interviews with the NRCS Conservation Engineering Division (CED), Conservation Planning Division (CPD), Easement Programs Division (EPD), Ecological Site Division (ESD), Resources Inventory and Assessment Division (RIAD), and Soil Survey Division (SSD).
2. Developing a DEM Whitepaper presenting data requirements and NRCS business cases for National High Resolution Elevation Acquisition.
3. Composing a DEM Funding and Implementation Plan, to include summaries of NRCS elevation requirements.
4. Presenting and conveying this plan in the form of presentations and briefings.

This DEM Whitepaper addresses both items 1 and 2 above.

NRCS Elevation Requirements

NRCS elevation requirements were determined in three ways:

1. Over 200 responses to the Survey Monkey questionnaire at Appendix B.
2. Input from participants at three NRCS regional DEM workshops: (1) Central Region, Lincoln, NE, August 11-13, 2009; (2) Eastern Region, Greensboro, NC, December 8-10, 2009; and (3) Western Region, Denver, CO, March 2-3, 2010.
3. Interviews with NRCS headquarters staff during meetings and presentations on ____________.

Responses to Survey Monkey questions, plus comments from participants at the NRCS regional DEM workshops, indicated occasional misunderstanding of some terms used in the questionnaire. These terms included DEMs, DTMs, DSMs, TINs, Terrains, mass points, breaklines, orthometric heights, ellipsoid heights, hydro-enforcement, and DEM derivatives (hillshades, slope, aspect and curvature).

Appendix A, *DEM Primer*, was added to this DEM Whitepaper to define and illustrate these terms/products and to explain the primary technologies (photogrammetry, IFSAR and LiDAR) used today for production of digital elevation data. Appendix A ends with a comparison of the National Standard for Spatial Data Accuracy (NSSDA) and other standards for accuracy testing of digital elevation data relative to their *equivalent contour interval* traditionally used with the National Map Accuracy Standard (NMAS) developed for paper topographic maps.

Major NRCS elevation requirements are summarized as follows:

- Strong preference for LiDAR datasets (question 5).
- Strong preference for Digital Terrain Models (DTMs), with many requiring both DTMs and Digital Surface Models (DSMs) (question 10).
- Approximately equal preference for contours and digital elevation data, e.g., mass points, breaklines, TINs, Terrains, and DEMs (question 12). Contours are used for visual analyses of the terrain, and digital elevation data are used for automated analyses and diverse forms of 3D visualization. Today, contours are produced from digital elevation data; therefore, all users actually require digital elevation data whether they realize it or not.
- Strong preference for DEMs with 1 meter post spacing, with most others needing either 2 meter or 5 meter DEM post spacing (question 13).
- Strong preference for ESRI Grid format (question 14).
- Strong preference for DEMs that are hydro-enforced (question 16).
- Elevation data updates every 5 to 10 years (question 18).
- For vertical accuracy of elevation data, strongest requirement for 1-foot contour accuracy, i.e., vertical accuracy of 6 inches at the 90% confidence level (question 28).
- For horizontal accuracy of elevation data, strongest requirement for map scale of 1" = 100', i.e., horizontal accuracy of 3.33 feet at the 90% confidence level (question 29)
- Near unanimous requirement for NAD 83 (horizontal datum), NAVD 88 (vertical datum), and UTM coordinates (questions 32, 33 and 34).

- Clear preference for meters as horizontal units (question 35) and slight preference for meters as vertical units (question 36).

Question 48 was worded as follows: "The vertical accuracy of elevation data has the most direct correlation to the overall cost of an elevation dataset. As stated above, how would you best describe your justification for vertical accuracy?" The following replies were received from those who chose to answer this question:

- 54 replied: "Whereas we need elevation data with the vertical accuracy specified, we could accept something less."
- 38 replied: "We absolutely must have elevation data with the vertical accuracy specified."
- 13 replied: "Our specified vertical accuracy could best be summarized as 'nice to have' rather than necessary."
- 10 replied with other comments indicating that accuracy requirements would be determined by each project; however, several recommended that elevation data be obtained at the highest requirement level which can then be generalized for other projects that require less accuracy.

In discussing question 48 with attendees at the three NRCS regional DEM workshops, those with firm requirements for the highest accuracy point cloud data appeared to be soil scientists and engineers, whereas most NRCS users did not need point cloud data but simpler DEMs and derivatives.

NRCS Business Cases for High Resolution DEMs

DEM Project Applications

Appendix C provides detailed responses to Question 8 which asked respondents to summarize the user applications and programs for which they require high resolution elevation data. Based on keywords used in responses to this question, user DEM applications were ordered from top to bottom as shown at Table 1. The Number column indicates the number of individual responses that identified the keywords used. Please note that these keywords were not specified in the question but were entered by respondents in their narrative input. The X's in the subsequent columns were entered by attendees at the Eastern Region DEM Workshop, indicating their beliefs as to DEM applications within the six NRCS Divisions. Appendix D provides lessons learned (positive and negative) from the use of high resolution elevation data for selected applications within NRCS.

Soils Mapping

With 73 individual responses for "soils mapping," the message was loud and clear that high resolution and high accuracy point cloud and DEM derivatives (hillshades, slope, aspect and curvature) are absolutely essential for soils mapping, at the top of the list in Table 1; in support of this application, Tom D'Avello voluntarily authored Appendix G to this Whitepaper: "NRCS Soil Survey Division DEM Requirements."

Table 1. DEM Application Priorities with Usage by NRCS Division

Keywords	Number	CED	CPD	EPD	ESD	RIAD	SSD
Soils Mapping	73	X	X	X	X	X	X
Engineering	52	X	X		X		
Wetlands	51	X	X	X	X	X	X
Conservation	47	X	X		X		
3-D Modeling and Terrain Analysis	36	X	X	X	X	X	X
Engineering Design	23	X					
Easements	21		X	X	X		
Planning	20	X	X	X	X	X	X
Dams	18	X	X		X		X
Hydrology & Hydraulics	18	X	X	X	X	X	
Floodplain Mapping/Analysis	14	X	X	X	X	X	X
Forest and/or Vegetation Analysis	14		X	X	X	X	X
Irrigation Systems	11	X	X		X	X	X
Precision Agriculture	9		X				X
Watershed Management	9	X	X	X	X	X	X
Erosion Control	8	X	X	X		X	X
Pipelines	8	X	X				X
Ponds	7	X	X	X	X	X	X
Cultural Resources	6	X	X	X	X	X	X
Resources Inventory	6		X		X	X	X
Stream Restoration	5	X	X	X	X		
Water Resources	4	X	X		X	X	X
Ecology	3		X	X	X		X
11 Miscellaneous Applications	1	X	X	X	X	X	X

Engineering

With 52 individual responses using the term "engineering" plus 23 additional responses using the term "engineering design," it was clear that diverse engineering applications within NRCS also have firm requirements for high resolution and high accuracy point cloud data and DEM derivatives. Other DEM applications often involve engineering, to include: 3-D modeling and terrain analysis (36), dams (18), hydrology & hydraulics (18), floodplain mapping and analysis (14), irrigation systems (11), pipelines (8), erosion control (8), ponds and pond design (7), and stream restoration (5). Typically in all organizations, such engineering applications have the greatest need for elevation data of the highest accuracy and resolution, such as depicted in Figures 1 and 2 on the next page with DEMs having 2-meter cell sizes.

Other Applications

Other applications were referenced that may not absolutely require elevation data of the highest accuracy and resolution, to include: wetlands (51), conservation (47), easements (21), planning (20), forest and/or vegetation analysis (14), watershed management (9), cultural resources (6), resources inventory (6), water resources (4), and ecology (3). These applications do not clearly require 2-meter DEM cell sizes and could perhaps utilize lesser resolution DEMs, intelligently thinned by using ESRI Terrain pyramids and slope gradient maps shown in Figure 3 through Figure 6. However, it is intuitively obvious that all such applications would benefit from the higher resolution elevation data which is standard in LiDAR datasets acquired for other major federal DEM producers, i.e., USGS, FEMA and NOAA, as well as states that typically require 2-meter DEM resolution with 2-foot contour accuracy or better. Conservation planners, for example, might not realize that they need higher resolution DEMs, but when they see Figures 1 through 6, they would quickly focus on Figures 1 and 2 and say: "That's what I need!"

Precision Agriculture

The biggest surprise from our questionnaire was the relatively few responses (9) that indicated NRCS' use of high resolution DEMs in support of precision agriculture. The "National Height Modernization Study: Report to Congress," prepared by NOAA in 1988, estimated that high resolution DEMs combined with a nationwide differential GPS network would have estimated value to constituents of $1.7 billion for precision farming for planned application of water, fertilizer, pesticides, etc. This NOAA study predicted that, with GPS-based precision farming technology, farmers would be able to go from farming by the acre to farming by the square foot while also reducing a major source of non-point pollution. Precision farming systems would gather data on tillage, seeds planted, weeds, insect and disease infestations, cultivation and irrigation, and *location-stamp* that data with GPS information. Using these data, farmers could micromanage every step of the farming process. For example, a farm GIS database might include layers on field topography (DEMs), soil types, surface drainage, sub-surface drainage, soil testing results, rainfall, irrigation, chemical application rates, and crop yield. Once this information is gathered, farmers could analyze it to understand the relationships between the different elements that affect crop yields.

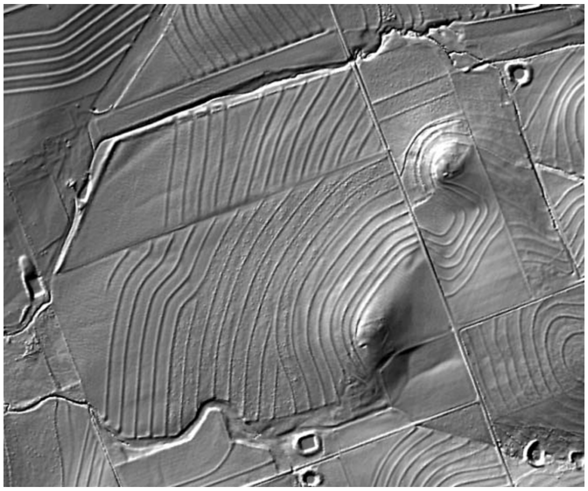


Figure 1. DEM hillshade, 2-meter cell size with full Z resolution.

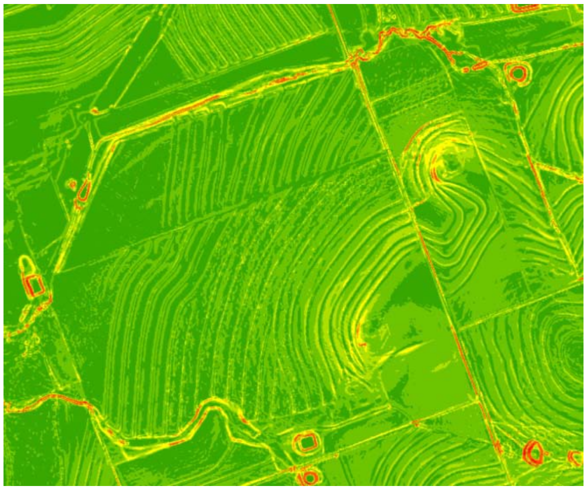


Figure 2. Slope gradient map from data in Figure 1.

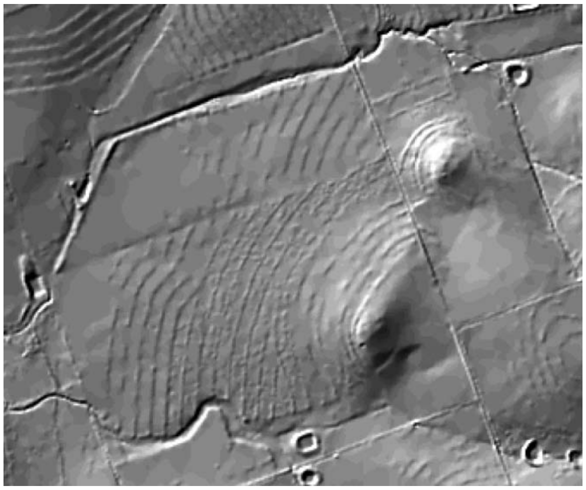


Figure 3. DEM hillshade, pyramid level 1 with 5 meter cell size; 0.25-meter Z tolerance

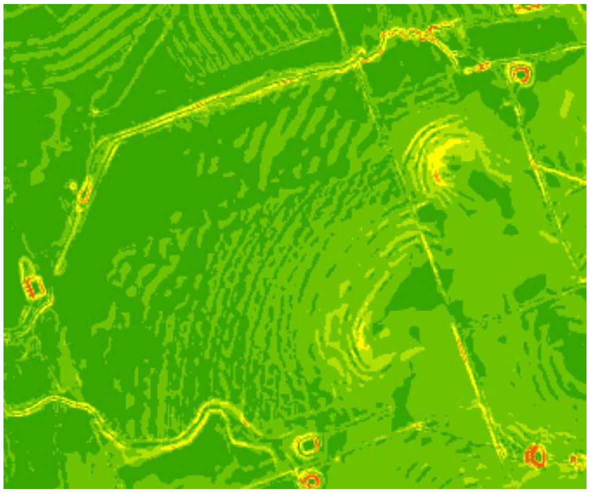


Figure 4. Slope gradient map from data in Figure 3.

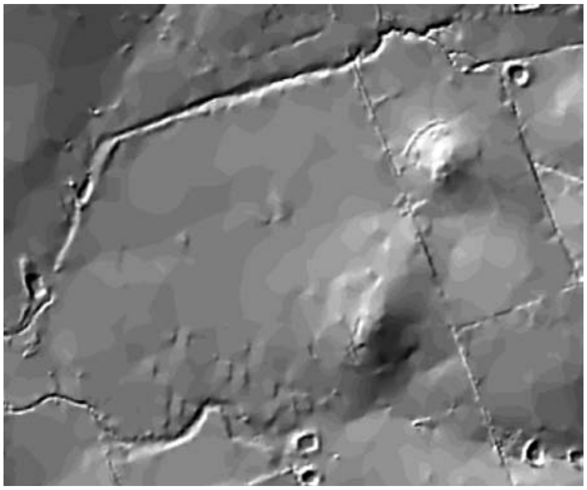


Figure 5. DEM hillshade, pyramid level 2 with 5-meter cell size; 0.5-meter Z tolerance.

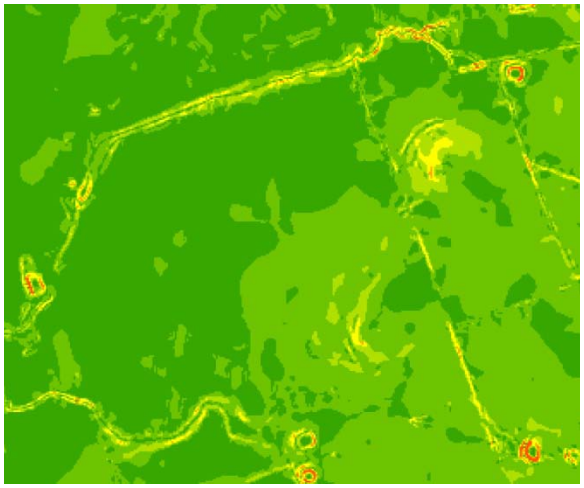


Figure 6. Slope gradient map from data in Figure 5.

NOAA's "National Height Modernization Study" report states: "Precision agriculture enables farmers to implement *Best Management Practices (BMPs)* through the careful control of the quantity of water, fertilizer and pesticides placed on different areas of land, depending upon soil type and condition, slope, and other factors. Height data have special relevance because slopes determine the direction in which runoff will flow, and runoff could adversely impact unintended areas. For these reasons, the agriculture industry needs good vertical and horizontal control and accurate Digital Elevation Models (DEM)."

Dewberry has been unable to determine whether these predicted benefits of precision agriculture have failed to develop; whether they pertain primarily to large agribusinesses rather than small farmers; or whether NRCS has deferred precision agriculture technical issues to the commercial industry that markets the hardware and software needed for the practice of precision agriculture.

Benefits Identified in Survey Questionnaire

Tangible benefits measure, in dollar savings, the impact of an activity on people, equipment, time, space and facilities, and support materials. *Intangible benefits* are subjective issues that can strongly influence the decision to undertake an effort, but can seldom be measured in dollar terms.

LiDAR Tangible Benefits

Question 56 asked respondents to identify the tangible benefits for NRCS by using LiDAR data:

- 96 respondents indicated NRCS cost reductions by using LiDAR
- 62 respondents indicated NRCS cost avoidance by using LiDAR
- 7 respondents indicated increased revenue for NRCS by using LiDAR
- 25 respondents described other tangible benefits for NRCS by using LiDAR

Question 57 asked respondents to briefly explain the tangible benefits for NRCS by using LiDAR data. Appendix E quotes the 32 responses that pertained to LiDAR time and cost savings for NRCS.

LiDAR Intangible Benefits

Question 58 asked respondents to identify the intangible benefits for NRCS by using LiDAR data:

- 104 respondents indicated more accurate information for NRCS by using LiDAR
- 94 respondents indicated better and/or timelier decision-making by NRCS when using LiDAR
- 90 respondents indicated better support of the NRCS/Division mission when using LiDAR
- 60 respondents indicated improved environmental protection by NRCS when using LiDAR
- 37 respondents indicated better reporting by NRCS when using LiDAR
- 37 respondents indicated better NRCS support of states when using LiDAR
- 27 respondents indicated improved public safety by NRCS when using LiDAR

Question 59 asked respondents to briefly explain the intangible benefits for NRCS by using LiDAR data. Appendix E quotes 52 responses that pertained to improved NRCS products and services, and 12 responses that pertained to improved timeliness from NRCS' use of LiDAR.

IFSAR Tangible Benefits

Question 63 asked respondents to identify the tangible benefits for NRCS by using IFSAR data:

- 44 respondents indicated NRCS cost reductions by using IFSAR
- 28 respondents indicated NRCS cost avoidance by using IFSAR
- 4 respondents indicated increased revenue for NRCS by using IFSAR
- 11 respondents described other tangible benefits for NRCS by using IFSAR

Question 64 asked respondents to briefly explain the tangible benefits for NRCS by using IFSAR data. Appendix E quotes the 8 responses that pertained to IFSAR time and cost savings for NRCS.

IFSAR Intangible Benefits

Question 65 asked respondents to identify the intangible benefits for NRCS by using IFSAR data:

- 46 respondents indicated more accurate information for NRCS by using IFSAR
- 42 respondents indicated better and/or timelier decision-making by NRCS when using IFSAR
- 37 respondents indicated better support of the NRCS/Division mission when using IFSAR
- 25 respondents indicated improved environmental protection by NRCS when using IFSAR
- 20 respondents indicated better reporting by NRCS when using IRSAR
- 16 respondents indicated better NRCS support of states when using IFSAR
- 11 respondents indicated improved public safety by NRCS when using IFSAR

Question 66 asked respondents to briefly explain the intangible benefits for NRCS by using IFSAR data. Appendix E quotes 11 responses that pertained to improved NRCS products and services, and 5 responses that pertained to improved timeliness from NRCS' use of IFSAR.

Appendix E also quotes three responses that identified disadvantages of IFSAR relative to LiDAR. Those disadvantages are consistent with known disadvantages explained in Appendix A of this whitepaper.

Benefits Identified in NRCS Regional DEM Workshops

During the three NRCS regional DEM workshops, attendees were very vocal about their benefits from using high resolution elevation data. Most attendees had previously responded to the Survey Monkey questionnalre. The most typical response from workshop attendees can be synopsized in the Conclusions listed below.

Benefits Identified in NRCS Headquarters Interviews

Conservation Engineering Division (CED)

Need relevant image example from Dwain, plus highlights of interview info with CED.

Conservation Planning Division (CPD)

Need relevant image example from Dwain, plus highlights of interview info with CPD.

Easement Programs Division (EPD)

Need relevant image example from Dwain, plus highlights of interview info with EPD.

Ecological Site Division (ESD)

Need relevant image example from Dwain, plus highlights of interview info with ESD.

Resources Inventory and Assessment Division (RIAD)

Need relevant image example from Dwain, plus highlights of interview info with RIAD.

Soil Survey Division (SSD)

Need relevant image example from Dwain, plus highlights of interview info with SSD.

National Standards for LiDAR and IFSAR Data

In 2003, the Federal Emergency Management Agency (FEMA) published Appendix A, *Guidance for Aerial Mapping and Surveying,* to its "Guidelines and Specifications for Flood Hazard Mapping Partners." FEMA's Appendix A has long been considered as the LiDAR industry's *de facto* standard. However, FEMA never intended to establish standards broadly used by others; instead FEMA only intended to establish their own minimum requirements for elevation data used for floodplain mapping, to include procedures for accuracy testing of LiDAR data for vegetation categories representative of flood plains being mapped for the National Flood Insurance Program. In the future, FEMA intends to defer to the USGS which has Title 16 responsibilities for elevation data among federal agencies.

The USGS has recently published "Base LiDAR Specifications for the National Geospatial Program (NGP)." These specifications were coordinated with NRCS and other members of the National Digital Elevation Program (NDEP) who are routinely invited to submit recommended changes for consideration. The current version, V12, is at Appendix H of this whitepaper. V12 requires $RMSE_z$ of 15-centimeters in open terrain (better than 2-foot but poorer than 1-foot contour accuracy). The 15-centimeter $RMSE_z$ matches what is currently routinely achieved by standard processes now in general use by the LiDAR community without paying higher prices for flying at lower altitudes with narrower flight line spacing. The standard accuracy in the LiDAR industry is expected to improve in the years ahead as the technology matures with improved hardware and software; then USGS is expected to "tighten" its Base LiDAR Specifications accordingly.

USGS also expects these specifications to be modified and improved through lessons learned in their recent implementation. USGS LiDAR task orders issued since late 2009 have used these specifications, and all such datasets are expected to become publicly available via the National Elevation Dataset (NED), as 1/27th arc-second data, and via USGS' Center for LiDAR Information Coordination and Knowledge (CLICK). CLICK is a virtual Web-based center with the goal of providing a clearinghouse for LiDAR information and point cloud data from all sources willing to share their data with others.

There is no national standard for IFSAR data, but a *de facto* standard has been established by Intermap Technologies, Inc. which has produced the NEXTMap USA product, licensed for a fee and available for all states in the U.S., except for Alaska. The DSM, DTM and ORI core products have been defined, and their details and technical specifications are published in the Intermap Product Handbook and Quick Start Guide which can be found at www.intermap.com on the Resource Center tab.

Conclusions

1. For most common applications, NRCS soil scientists, engineers and analysts clearly need high resolution, high accuracy digital elevation data to perform needed terrain analyses and make better decisions in hours, than it currently makes in days or weeks, while minimizing the need for traditional field surveys that are time-consuming and expensive.
2. Good digital elevation data are needed throughout NRCS in order to provide the timely and quality products and services required for successful mission accomplishment in the 21st century. Good digital elevation data and derivative products are a key to NRCS mission success.
3. It is slow, expensive and wasteful when NRCS personnel do not have access to needed digital elevation data but are forced to rely upon 10-foot contours from USGS topographic quad maps, for example, or digital elevation data produced from those contours. The cost of accurate, high resolution digital elevation data, including 1-foot or 2-foot contours produced from such data, literally pays for itself through savings-in-kind elsewhere throughout NRCS.
4. NRCS not only needs high resolution elevation data, it needs the supporting IT infrastructure needed to store and disseminate the data to users. It also needs computer hardware, software and training for specialized NRCS applications.
5. The USGS Base LiDAR Specifications for the National Geospatial Program (Appendix H) are very similar to specifications required by NRCS for most applications, with the exception that NRCS generally needs elevation data to be *hydro-enforced*, an additional step for processing of bridges beyond USGS' *hydro-flattening* of lakes and streams (see Appendix A for these definitions).
6. LiDAR data acquisition for small NRCS project areas would be very expensive per square mile. NRCS dollars would go much further if used to influence USGS priorities for the National LiDAR Initiative, as coordinated through the National Digital Elevation Program (NDEP), for which large area coverage can be acquired at relatively low unit costs for NDEP partner agencies that fund and prioritize projects of mutual benefit for larger project areas.

Recommendations

The following are Dewberry's recommendations, based partly on Appendix F recommendations from NRCS employees?

1. NRCS should acquire the IT infrastructure necessary to store and disseminate extremely large elevation datasets to users, including Web servers and computer hardware and software needed for specialized NRCS applications. Tim Blak to expand here.
2. In order to avoid needless proliferation of different LiDAR specifications for different Federal agencies, NRCS should utilize the USGS "Base LiDAR Specifications for the National Geospatial Program (NGP)" while continuing to work with USGS to "tweak" those specifications as needed, rather than publish separate NRCS specifications for competing products. Whether NRCS contracts for its own data, or provides funds to USGS for such contracting, the goal is to avoid duplication of effort, to avoid having elevation datasets of different quality and usability, and to obtain consistent nationwide coverage available to all, to include standard procedures for QA/QC of the elevation data, including metadata.
3. NRCS should establish best business practices for executing its most common DEM user applications, using Table 1 as a starting point for defining DEM applications with the most common usage within NRCS. These best business practices must account for the fact that common applications may have uncommon needs in supporting the missions of different NRCS Divisions. Those who produce soils maps, for example, have very different needs from others who use soils maps.
4. NRCS should determine which available commercial software is best for processing of standard elevation derivative products and acquire such software for selected offices only. NRCS should also develop additional GIS software tools for processing and analyzing digital elevation data to most efficiently execute specific NRCS applications not currently standardized in commercial software. Because many NRCS GIS personnel feel that they currently are "on their own" to figure things out, the goal is to develop common solutions for common problems. For some applications, e.g., hydrologic and hydraulic modeling, pond design and dam breach analyses, commercial software may already be available for standard usage within NRCS.
5. NRCS should develop a DEM User's Handbook to explain: how to determine what elevation data are available; how to access the data; how to process the data for standard products using commercial software; and how to use NRCS-developed software tools for specialized applications. The goal is to "level the playing field" by enabling many more NRCS employees to utilize the most effective and efficient standard processes within the agency.
6. To address the above recommendations, NRCS should establish a top-level GIS/remote sensing working group to develop a plan of action for implementation of the above recommendations, and to develop procedures for obtaining input from the field to ensure diverse requirements are heard and understood.

Appendix A – DEM Primer

DEM Products and Definitions

What's a DEM? What's the difference between a DEM, DTM and DSM? What are mass points and breaklines? What's a TIN? What's a Terrain? How are DEMs produced from photogrammetry? IFSAR? LiDAR? What are the capabilities and limitations of these technologies for satisfying NRCS needs? What is a hydro-enforced DEM? These questions, and others relevant to NRCS, are answered in this Appendix. Most definitions and figures are extracted from the 2nd edition of "Digital Elevation Model Technologies and Applications: The DEM Users Manual" published in 2007 by the American Society for Photogrammetry and Remote Sensing (ASPRS, 2007), edited by the author of this NRCS DEM whitepaper.

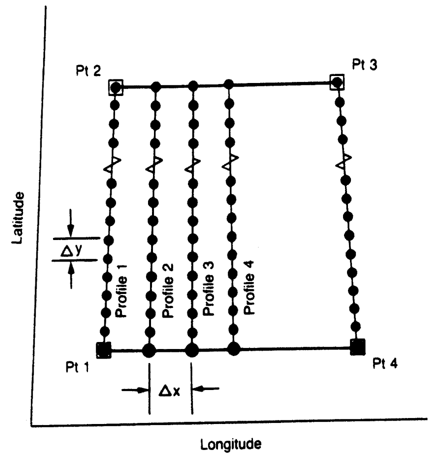


Figure A.1. DEM based on geographic coordinates, as in the NED, where Δx and Δy are arc-seconds of longitude and latitude, respectively.

DEMs

DEM (Digital Elevation Model) is a popular acronym with multiple definitions:

- As used in the name of this whitepaper, a DEM is used in a generic sense for digital topographic and/or bathymetric data in all its various digital forms, including mass points, breaklines, TINs, Terrains, and DTMs. Unless specifically referenced as a Digital Surface Model (DSM), the generic DEM normally implies x/y coordinates and z-values (elevations) of the bare-earth terrain, void of vegetation and manmade features.
- As used by the U.S. Geological Survey (USGS), a DEM is the digital cartographic representation of the elevation of the land at regularly spaced intervals in x and y directions, using z-values referenced to a common vertical datum. There are several different standard USGS DEMs archived in the National Elevation Dataset (NED) based on 1-arc-second, 1/3-arc-second, and 1/9-arc-second grid spacing (see Figure A.1).
- As typically used throughout the U.S., a DEM has bare-earth z-values at regularly spaced intervals in x and y, where Δx and Δy are measured in feet of meters to even units (see Figure A.2); however, grid spacing, datum, coordinate systems, data formats, and other characteristics may vary widely. This is often called a gridded DEM where grid spacing = Δx and Δy, e.g., 1 meter.

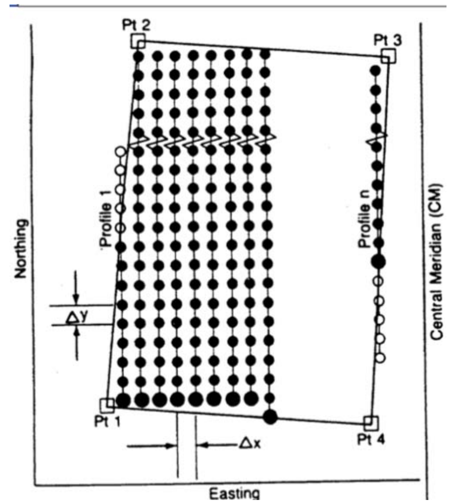


Figure A.2. DEM based on rectangular coordinates, normally UTM or state plane coordinates, where Δx and Δy are even units measured in feet or meters.

DTMs and DSMs

Digital Terrain Models (DTMs) are similar to DEMs in representing the bare-earth terrain surface, but they may also incorporate the elevation of significant topographic features on the land and mass points and breaklines that are irregularly spaced to better characterize the true shape of the terrain itself. The net result of DTMs is that the distinctive terrain features are more clearly defined and precisely located, and contours generated from DTMs more closely approximate the real shape of the terrain. Such DTMs are normally more expensive and time consuming to produce than uniformly spaced DEMs because breaklines are ill suited for automated collection.

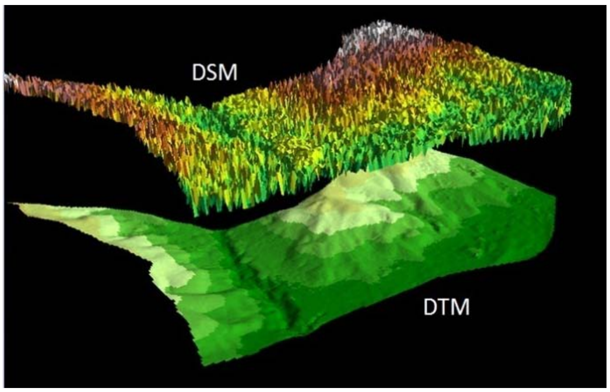


Figure A.3. Digital Surface Model (DSM) of treetops and Digital Terrain Model (DTM) of the bare-earth terrain beneath the trees.

DTMs are technically superior to standard gridded DEMs for many applications relevant to NRCS. Please note that the DTM shown in Figure A.3 has not yet been hydro-enforced with breaklines to clearly delineate the shorelines (if any) of the drainage feature or to enforce the downward flow of water. If the drainage feature is dry, it is customary to retain the natural up-and-down undulations of the dry terrain, but if there is a stream here, it is customary to use breaklines to depict shorelines and to perform some type of hydro-enforcement to ensure the downward flow of water in hydrologic and hydraulic modeling.

Digital Surface Models (DSMs) are similar to DEMs or DTMs, except that they depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth. DSMs are especially relevant for telecommunications management, air safety, forest management, and 3-D modeling and simulations.

Figure A.3 shows both the DSM and DTM, color-coded by elevations. The elevation differences between the DSM and DTM are commonly used to evaluate the height of vegetation, relevant for some NRCS applications.

Mass Points and Breaklines

Mass points are irregularly spaced points, each with an x/y location and a z-value, typically (but not always) used to form a TIN or Terrain. They are normally generated by automated methods, e.g., by LiDAR or IFSAR scanners or photogrammetric auto-correlation techniques. When generated by automated methods, mass point spacing and pattern depend on characteristics of the technologies used to acquire the data.

Breaklines are linear features that may be used to maintain the smoothness or continuity of a surface (soft breaklines) or to describe a change in the smoothness or continuity of a surface, especially at the intersection between two surfaces with distinctly different slopes (hard breaklines).

A soft breakline ensures that known z-values along a linear feature are maintained (e.g., elevations along a pipeline or road centerline), and ensures that linear features and polygon edges are maintained in a TIN surface model by enforcing the breaklines as TIN edges; but a soft breakline does not define interruptions in surface smoothness. Soft breaklines are generally synonymous with 3-D breaklines because they are depicted with series of x/y/z coordinates.

A hard breakline defines interruptions in surface smoothness. A hard breakline is used to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are 3-D breaklines, they are often depicted as 2-D breaklines because features such as shorelines and building footprints are normally depicted with series of x/y coordinates only, e.g., shorelines digitized with x/y coordinates from digital orthophotos that include no elevation value.

Hydro breaklines are commonly used to define the land-water interface. This is especially relevant with LiDAR because LiDAR elevations on water are unreliable, i.e., sometimes the LiDAR measures the top of the water, sometimes it penetrates somewhat below the water surface, sometimes there is spectral reflectance, and often water absorbs the LiDAR pulse and there is no return. For lakes and double-line streams, it is common to use delineate hydro breaklines so that all LiDAR points within hydro features are classified to a special hydro class for water.

As an example, Figure A.4 represents a small island in the ocean, and the island includes hills and one interior lake with a small stream running through the hillside from the lake to the ocean. A scattered array of elevation points is shown on the island, as well as several types of breaklines. These few elevation points could have been carefully compiled by a photogrammetrist to reflect key spot heights, for example. Alternatively, one can imagine hundreds or thousands of similar mass points randomly acquired by a LiDAR or IFSAR sensor, as in Figures A.5 through A.8 below.

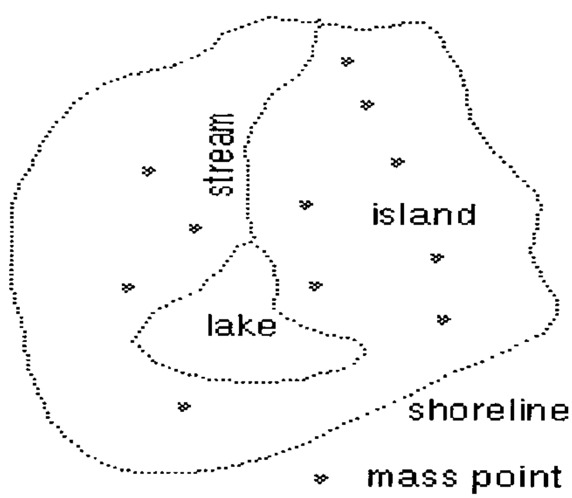


Figure A.4. Example of a few mass points on an island and three types of breaklines. LiDAR would have thousands to millions of such mass points. Also see Figure A.11, a TIN produced from this same data.

Figure A.4 also shows three breaklines. The island's shoreline with the ocean is a breakline, as is the shoreline of the interior lake; and the centerline of the stream is a third breakline. Each of these breaklines has unique challenges:

Breaklines for coastal shorelines are always problematic, primarily because of changing tide conditions. Aerial data acquisition for photogrammetry, LiDAR or IFSAR is almost always performed with straight, parallel flight lines. Because shorelines are not straight and parallel, elevation data is normally collected along coastal shorelines with different flight lines at different stages of the tide, resulting in varying elevations along the land/water interface. Furthermore, mean tide level along the north shore of Puerto Rico, for example, is quite different from mean tide level along the south shore of Puerto Rico. Tide-coordinated acquisition (intended for low-tide conditions) is much more expensive and often futile if the intent is to map a single elevation for an entire coastal shoreline. Indeed, natural variations in mean sea level throughout our nation's coastlines were the main reason why the U.S. converted from the National Geodetic Vertical Datum of 1929 (NGVD 29), which assumed mean sea level of 26 tide stations all equaled zero elevation (whereas those zero elevations actually differed by several feet), and the North American Vertical Datum of 1988 (NAVD 88) which is based on mean sea level at only on a single tide station. Fortunately for NRCS, coastal breaklines are not of significant concern.

Breaklines for lake and reservoir shorelines are relatively easy. Unless a "z-lock" function is used with photogrammetry or lidargrammetry to maintain a single elevation, lake shorelines would be uncertain, often with undulating elevations because of natural variations in the terrain, vegetation, and even fallen trees and rubble along shorelines and surrounding areas. However, DEM software exists to flatten lake shorelines, so this is not an expensive issue to solve. Figure A.5 shows pre-compilation LiDAR points for a reservoir that is mostly dry, and Figure A.6 shows the results of a z-lock function which defined a shoreline for this lake. Users recognize that a lake or reservoir shoreline changes with different water levels, and they expect to see a well defined shoreline (Figure A.6), not an undefined shoreline (Figure A.5). Considering the shape of the surrounding embankments, this reservoir could be mapped to show the shoreline if the reservoir were full; however it is standard practice for map makers to map *in situ* conditions and not future conditions. Furthermore, it is always better to map hydrologic features that are dry or at low water levels so that we know the elevations of the topography when under water.

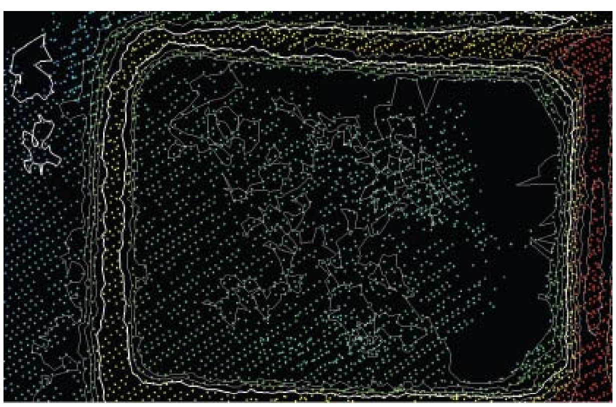


Figure A.5. Pre-compilation LiDAR mass points for a reservoir that is mostly dry.

Figure A.6. Breakline for water boundary within which LiDAR points are reclassified as water.

For NRCS purposes, the availability of high density LiDAR data enables quick and easy pond design from which water depth, area, and volume are accurately computed with simple GIS tools.

<u>Breaklines for flowing streams</u> are expensive because they are produced manually to ensure the downward flow of water. The tops of bridges and culverts are initially mapped, but they need to be "cut" so that they do not appear as dams that block the flow of water. More importantly, single-line and double-line streams require flowlines or hydro breaklines that model the downward flow of water. Making rivers flat from bank to bank, yet flowing smoothly downhill, is not a simple task. USGS accepts river polygons that are individually flat but stair-stepped in the downhill direction. Meandering and braided streams become especially complex, especially for users that do not accept the stair-stepped solution. Figure A.7 shows a pre hydro-enforced ground model, and Figure A.8 shows the hydro-enforced double-line stream, including 3D breaklines at the top and bottom of both stream banks as used for hydraulic modeling. When elevation points are measured systematically by photogrammetry, LiDAR or IFSAR, none of these breaklines would be immediately obvious to users. Elsewhere, for a dry drainage feature, Figures A.9 and A.10 show a 2.5-D breakline that is not hydro-enforced.

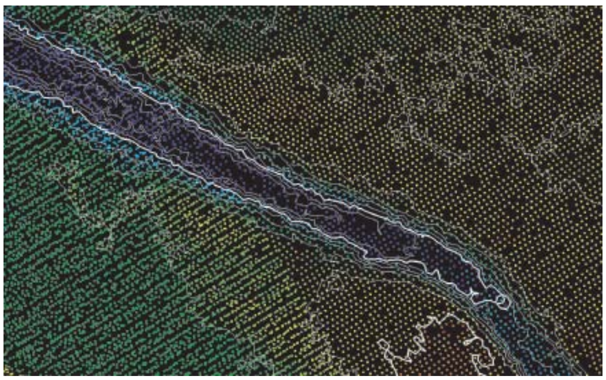


Figure A.7. Pre hydro-enforced ground model with unreliable LiDAR points in the river.

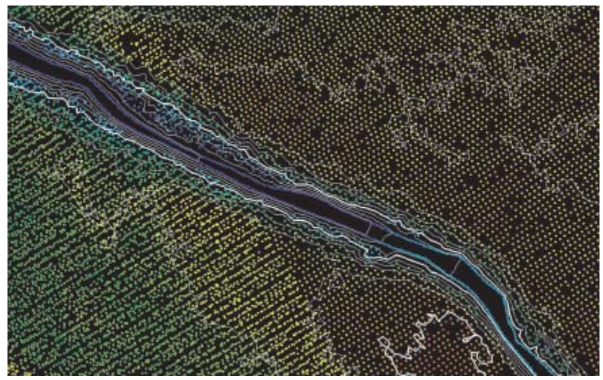


Figure A.8. Hydro-enforced stream with LiDAR points reclassified as water between dual breaklines.

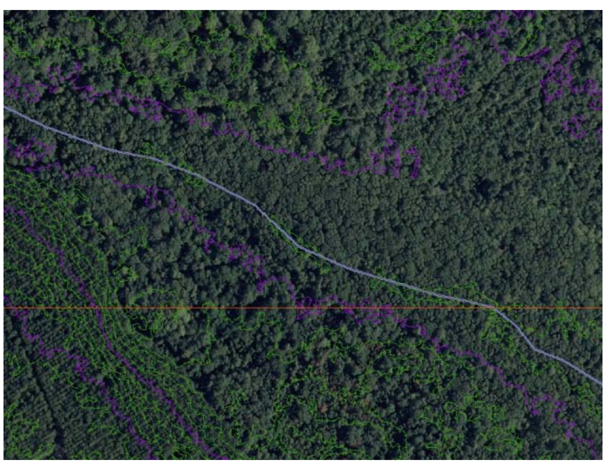


Figure A.9. Orthophoto with 2.5-D breakline (white line) of dry drainage feature, 1-ft contours (green lines) and 5-ft index contours (purple lines) mapped by LiDAR in extremely dense vegetation in Florida.

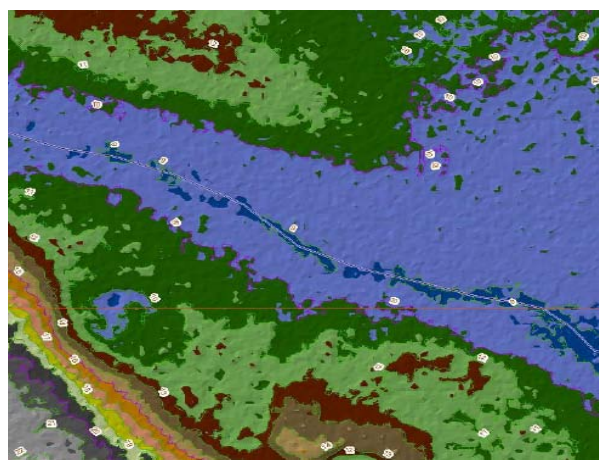


Figure A.10. The 2.5-D breakline was compiled from this Terrain, color-coded within 1-ft contour intervals, and showing depressions or sinks (blue polygons) in the dry drainage channel.

Breaklines for dry drainage features are produced by 2.5-D techniques. A human compiler digitizes the x/y coordinates of linear features from any source, including digital orthophotos , and then software tools are employed to drape the planimetric vectors over a Terrain to obtain the z-values that naturally undulate up and down as shown at Figure A.10. The small white circles contain numbers with contour elevation values. In this example, the linear feature could not have been digitized from the orthophoto at Figure A.9 because the vegetation was too dense to see what was beneath.

This example demonstrates the major advantage of LiDAR. Neither imagery nor IFSAR would have been able to penetrate through or between the trees to map the bare-earth terrain beneath. If the dry drainage feature had not been obscured by vegetation, photogrammetry would have been a viable way to compile the breakline of this dry drainage feature; if so, the flow line would still undulate up and down to show the real terrain. It would be considered wrong to hydro-enforce a dry drainage feature; the "best of all worlds" is to be able to map a drainage feature while it is dry so that users know the true shape of the topography that may sometimes be under water.

Procedures for generation of accurate breaklines from randomly-spaced mass points are still evolving, although some such procedures yield reasonable approximations of those breaklines. Furthermore, it usually takes a human operator to recognize when drainage patterns pass under the visible surface because of bridges and culverts.

TINs and Terrains

A TIN (Triangulated Irregular Network) is a set of adjacent, non-overlapping triangles computed from irregularly spaced mass points with x/y coordinates and z-values. The TIN's vector data structure is based on irregularly-spaced point, line, and polygon data interpreted as mass points and breaklines and stores the topological relationship between triangles and their adjacent neighbors. Figure A.11 is an example of a simple TIN created from the mass points and breaklines shown in Figure A.4 above. TINs are excellent for calculation of slope, aspect, surface area and length; volumetric and cut-fill analysis; generation of contours, and interpolation of surface z-values. The TIN model is preferable to a DEM when it is critical to preserve the precise location of narrow or small surface features such as ditches or stream centerlines, levees, isolated peaks or pits in the data model. TIN triangles can be very small when there is high LiDAR point density, e.g., 1-meter nominal point spacing (NPS).

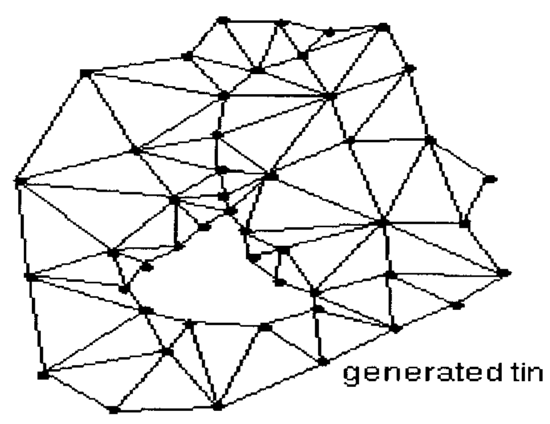


Figure A.11. A simple TIN produced from the mass points and breaklines in Figure A.4.

Once we have mass points and breaklines, or a TIN derived therefrom, a DEM can be produced by interpolating the elevations at the exact x/y coordinates computed for the DEM grid. This interpolation process yields a DEM surface that is less accurate than the dataset used for the interpolation, however, the DEM is normally easier to store in a GIS database.

A Terrain dataset is a multi-resolution, TIN-based surface built from measurements stored as features in a Geodatabase (see Figure A.12). Terrains have participating feature classes and rules, similar to topologies. Terrains efficiently index each source point measurement from a feature class or a set of feature classes. The Terrain establishes a set of user-defined viewing pyramid levels, each having fewer participating source points as the user zooms to smaller scales. Unlike an ESRI Grid or DEM file, the Terrains are generated by utilizing the actual surface points rather than interpolating elevation values for a cell in a raster file. This data storage and visualization method enables faster viewing or large area Terrains at small scales easier than most other elevation data types.

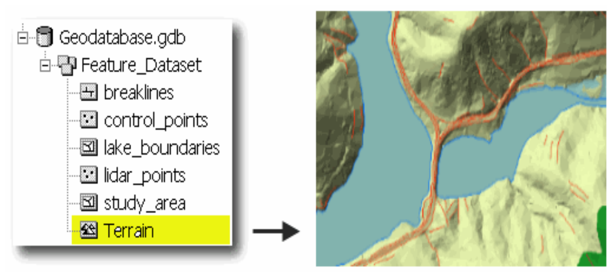


Figure A.12. Typically made from LiDAR, Terrains reside in the Geodatabase, inside feature datasets with the features used to construct them

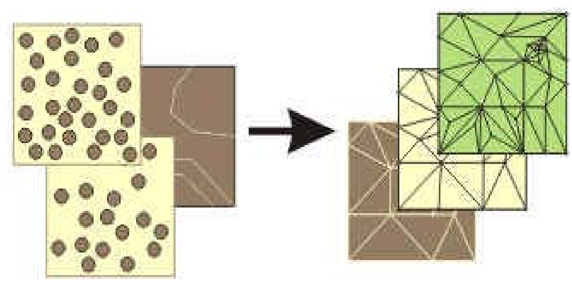


Figure A.13. An example of multiple source data participating in variable resolution TIN pyramids (Terrain dataset)

Common feature classes that act as data sources for Terrains include: (1) multipoint feature classes of 3D mass points created from a data source such as LiDAR; (2) 3D point and line feature classes created on photogrammetric workstations using stereo imagery or lidargrammetry; (3) study area boundaries used to define the bounds of the Terrain dataset. Terrain dataset rules control how features are used to define a surface, e.g., a feature class containing edge of pavement lines for roads could participate with the rule that its features be used as hard breaklines. This will have the desired effect of creating linear discontinuities in the surface.

Terrains are a relatively new data type that was first introduced with ArcGIS 9.2. They live inside feature datasets in personal, file or SDE Geodatabases. The feature classes in the feature dataset can participate in the Terrain or actually be embedded in the Terrain, which means that the source data could be moved off-line after the creation of the Terrain dataset. Figure A.13 illustrates how multiple types of feature classes can participate to generate TIN pyramids for the Terrain dataset. Terrain datasets solve many of the data storage and handling problems that plagued the traditional TINs, making them much more efficient to use and without decimation or generalization.

Contours

Contour lines are lines of equal elevation on a surface. Contours are used for human interpretation of the 3D terrain surface, whereas mass point, breaklines, TINs, Terrains, DEMs, DTMs and DSMs are better for computer display and analyses of the 3D surface. Whereas many NRCS personnel are most comfortable with contours for human analysis, they will find that the digital products described above will enable them to modernize their procedures and become much more efficient.

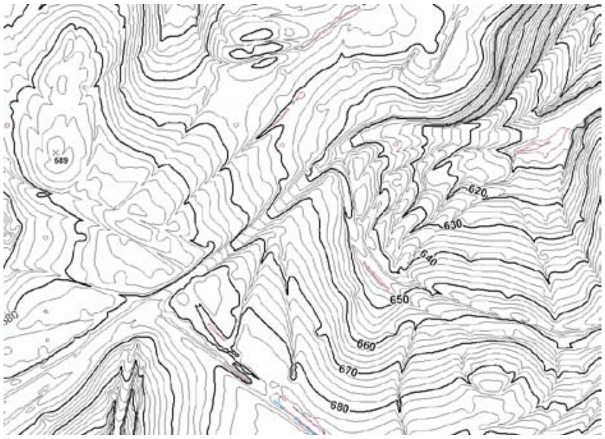


Figure A.14. Example of 2-foot contours that depict a road and drainage features.

Whereas it is difficult to keep paper maps with contour lines accurate and up-to-date, digital products are best suited for rapid update and analyses. Figure A.14 shows an example of contour lines that we have grown to know and love for visual analysis; but they are essentially worthless for automated analysis. Contours today are rarely produced by cartographers who carefully shaped each curve, but are produced by automated processing of DEMs, TINs or Terrains. Automated analytical tools do not use contours, but the other digital elevation data (DEMs, TINs, etc.) from which contours are derived.

DEM Mapping of Hydrographic Features

One of the decisions that NRCS faces is how hydrographic features should be processed in a DEM. There is no "one-size-fits-all" solution used nationwide. There are at least three similar terms used for DEM mapping of hydrographic features: (1) hydro-enforcement, (2) hydro-conditioning, and (3) hydro-flattening. The first two terms are defined in "Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition (ASPRS, 2007), and the third term has been recently coined by USGS for the Base Lidar Specification for the National Geospatial Program. Figure A.15 shows a typical stream and a bridge spanning that stream. Should the elevation of the bridge deck be retained in the DEM, thereby appearing to form a dam so that water cannot flow beneath, or should the elevations within the red polygon be reclassified so that water flows beneath the bridge, as shown in Figure A.16? Can NRCS accept the "TINning" in Figure A.16, or do we need streams to be hydro-enforced?

Figure A.15. Colorized digital image of a stream with bridge that would appear to dam the stream in a DEM, preventing the flow of water downstream.

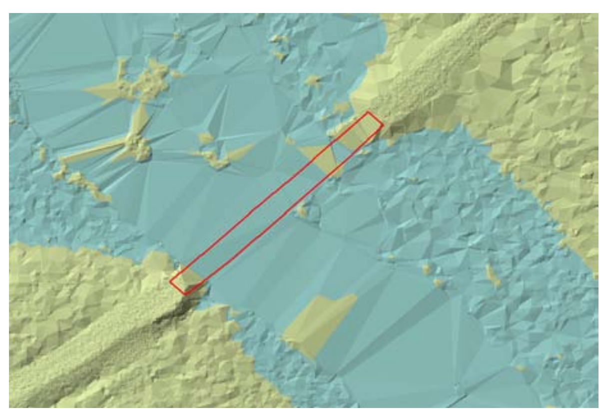


Figure A.16. An ESRI Terrain with the bridge reclassified; but the "TINning" still does not reflect shorelines or a smooth flow of water downstream.

Hydro-Enforcement

Hydro-enforcement is the processing of mapping water bodies so that lakes and reservoirs are level and so that both single-line and double-line streams flow downhill. For example, a DEM, TIN, or topographic contour dataset would have elevations removed from the tops of bridges so as to depict the terrain under those structures (see Figure A.16 above).

Hydro-enforcement enables hydrologic and hydraulic (H&H) models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels.

Hydro-enforced TINs or Terrains also utilize breaklines along stream centerlines and/or shorelines where these breaklines form the edges of TIN triangles. Figure A.17, for example, shows LiDAR mass points (red) plus higher points (yellow) that appear to be rocks. Figure A.18 shows the TIN of these mass points prior to hydro enforcement; at this point, it appears as though water cannot flow smoothly downstream. Using known water elevations near upstream and downstream bridges, Figure A.18 shows the addition of 3D breaklines for the stream centerline and both shorelines, with elevations that decrease uniformly, assuming a uniform gradient. While solving the needs for an engineer performing H&H modeling, this inadvertently changed the modeling of the landform along the entire length of the shorelines between these two bridges. Figure A.19 shows a small cliff along the north shore; and that cliff does not really exist. In performing such hydro-enforcement it is not uncommon for the water surface elevation to be higher than the surrounding terrain, per example at Figure A.20 and Figure A.21, because the gradient is not truly uniform.

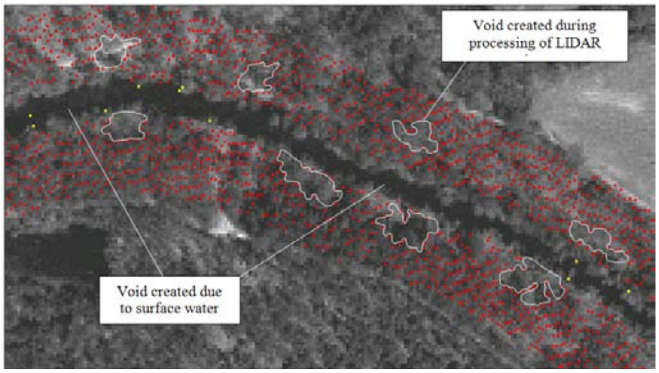


Figure A.17. LiDAR mass points on both sides of stream, including data voids from standing or flowing water.

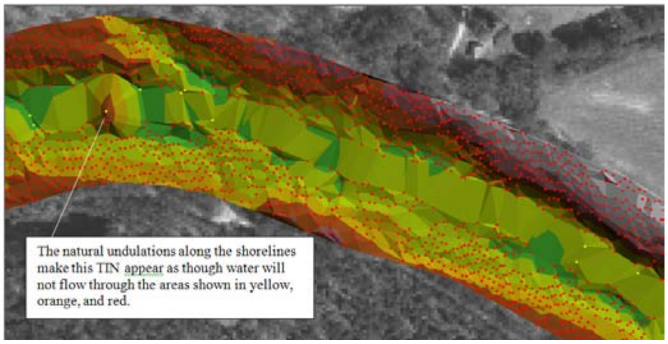


Figure A.18. Natural undulations along the shorelines make this TIN appear as though water will not flow through areas in red, orange or yellow.

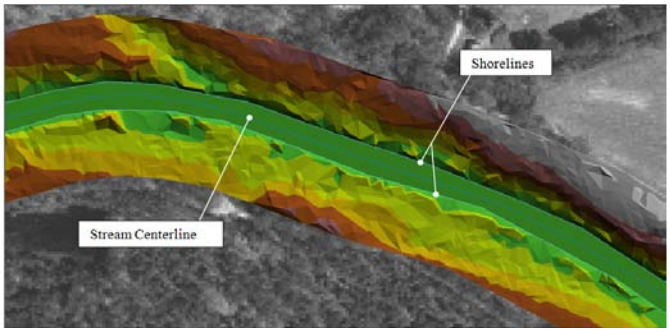


Figure A.19. Same TIN after addition of breaklines for artificial hydro-enforcement. This solves some problems but potentially creates other problems.

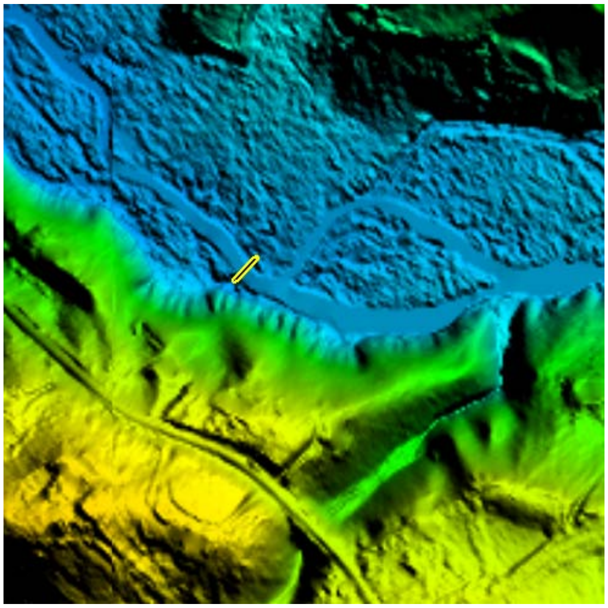


Figure A.20. Hydro-enforcement often causes the water to be too low in some cases, and too high in other cases, as shown in this example. See X-section.

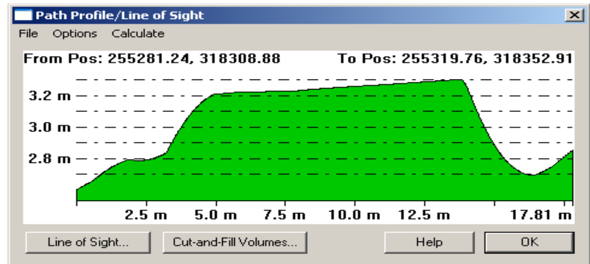


Figure A.21. The cross-section from Figure A.20 shows the water surface elevation higher than the surrounding terrain because the actual gradient is not truly uniform over many reaches of a stream.

When shoreline elevations decrease uniformly from known elevations upstream and known elevations downstream, some water surface elevations are too low and others too high when compared with the surrounding terrain. This can only be solved with labor-intensive hydro-enforcement methods that are non-linear.

For traditional hydro-enforcement of lakes and reservoirs, shore breaklines should have the same elevation for the entire shoreline, as previously demonstrated in Figures A.5 and A.6 above.

Hydro-Conditioning

Hydro-conditioning is the processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas *hydro-enforcement* is relevant to drainage features that are generally mapped (including bridges and large concrete box culverts), *hydro-conditioning* is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relationships/links among basins/catchments can be known for large areas. This term is specifically used when describing EDNA (Elevation Derivatives for National Applications), the dataset of NED (National Elevation Dataset) derivatives made specifically for hydrologic modeling purposes. In such cases, water would be modeled to flow over the top of roads rather than beneath the roads via small, unmapped culvert pipes.

Figure A.21. The red arrow points to a manmade "sink" caused by the entrance to a small culvert passing under the road. Such sinks are filled by hydro-conditioning.

Hydro-Flattening

This term was just coined by USGS in late 2009 and only relates to the creation of DEMs intended to be integrated into the USGS NED. It is not, at this time, a known or accepted term across the industry, but USGS hopes that its use and acceptance will expand beyond the USGS with the assistance of other industry leaders. USGS acknowledges that a "hydro-conditioned" surface has traditionally had its sinks filled and may have had its water bodies flattened; this is necessary for correct flow modeling within and across large drainage basins. USGS also acknowledges that "Hydro-enforcement" extends this conditioning by requiring water bodies to be leveled and streams flattened with the appropriate downhill gradient, and also by cutting through road crossings over streams (bridges and large box culverts) to allow a continuous flow path for water within the drainage. Both treatments result in a surface on which water behaves as it physically does in the real world, and both are invaluable for specific types of hydrologic and hydraulic (H&H) modeling activities. However, USGS believes that neither of these treatments is typical of a traditional DEM surface.

A traditional DEM such as the NED attempts to represent the ground surface more the way a bird, or person in an airplane, sees it after removal of man-made structures such as bridges and buildings. On this surface, natural depressions exist, and road fills create apparent sinks because the road fill and surface is depicted without regard to the culvert beneath. Bridges are removed in most all types of DEMs because they are man-made structures that have been added to the landscape.

For years, raster DEMs have been created from mass points and breaklines which in turn were created through photogrammetric compilation from stereo imagery. Photogrammetric DEMs and planimetric features inherently contain breaklines defining the edges of water bodies, coastlines, single-line streams, and double-line streams and rivers, as well as numerous other surface features. LiDAR technology, however, does not inherently collect the breaklines necessary to produce traditional DEMs or planimetric features. Breaklines have to be developed separately through a variety of techniques (described previously) and either used with the LiDAR points in the generation of the DEM or applied as a correction to DEMs generated without breaklines. In order to maintain the consistent character of the NED as a traditional DEM, the USGS National Geospatial Program (NGP) requires that all DEMs delivered have their inland water bodies flattened. This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset – only those breaklines necessary to ensure that the conditions exist in the final DEM consistent . Future DEMs are to be produced for USGS consistent with the following specifications for hydro-flattening:

Inland Ponds and Lakes

- ~2-acre or greater surface area (~350' diameter for a round pond)
- Flat and level water bodies (single elevation for every bank vertex defining a given water body)
- The entire water surface edge must be at or just below the immediately surrounding terrain
- Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers

Inland Streams and Rivers (Double-Line)

- 100’ nominal width; this should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100’ for short segments. Data producers should use their best professional judgment.
- Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
- The entire water surface edge must be at or just below the immediately surrounding terrain.
- Streams should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should not break at bridges. Bridges should be removed from DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

  Note: Cooperating partners may require collection and integration of single-line streams within their LiDAR projects. While the USGS does not require these breaklines to be collected or integrated, it does require that if used and incorporated into the DEMs the following guidelines are met:

  - All vertices along single-line stream breaklines are at or below the immediately surrounding terrain
  - Single-line stream breaklines are not to be used to introduce cuts into the DEM at road crossings (bridges, box culverts), dams, or other such features. This is hydro-enforcement and as discussed above, creates a non-traditional DEM that is not suitable for integration into the NED. All breaklines used to modify the surface are to be delivered to the USGS with the DEMs.

Non-Tidal Boundary Waters

- Represented only as an edge or edges within the project area; collection does not include the opposing shore.
- The entire water surface edge must be at or below the immediately surrounding terrain.
- The elevation along the edge or edges should behave consistently throughout the project. May be a single elevation (i.e., lake) or gradient (i.e., river), as appropriate.

Tidal Waters

- Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations.
- Tidal variations over the course of a collection, and between different collections, will result in discontinuities along shorelines. This is considered normal and these “anomalies” should be retained. The final DEM should represent as much ground as the collected data permits.
- Variations in water surface elevations resulting in tidal variations during a collection should NOT be removed or adjusted, as this requires either the removal of ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts the unavoidable irregularities in water surface.

Methodologies

The USGS does not require any particular process or methodology be used for breakline collection, extraction, or integration. However, the following general guidelines must be adhered to:

- Bare-earth LiDAR points that are in close proximity to breaklines should be excluded from the DEM generation process. This is analogous to the removal of mass points for the same reason in a traditional photogrammetrically compiled DTM. The proximity threshold for reclassification as "Ignored Ground" is at the discretion of the data producer, but in general should be approximately equal to the nominal post spacing (NPS).
- These points are to be reained in the delivered LiDAR point dataset and shall be reclassified as "Ignored Ground" (LAS class value = 10) so that they may be subsequently identified.
- Delivered data must be sufficient for the USGS to effectively recreate the delivered DEMs using the LiDAR points and breaklines without significant further editing.

In response to a Dewberry query, USGS replied: **"We require a gradient that closely follows the apparent or implied water surface elevation. Understanding that there will be situations -- in some cases numerous -- where this is either impractical or impossible (adjacent dataset collected at different times with different WSELs, etc.). In these cases, a stair-step transition is the only solution and is both acceptable and desired."** See both types of examples in Figures A.22/A.23 and A.24/A.25 below for two different but similar streams.

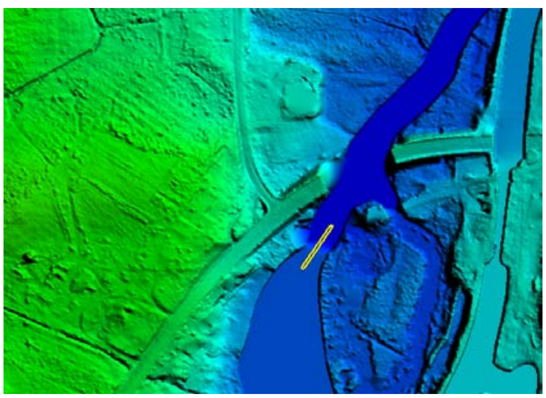


Figure A.22. Smooth gradient.

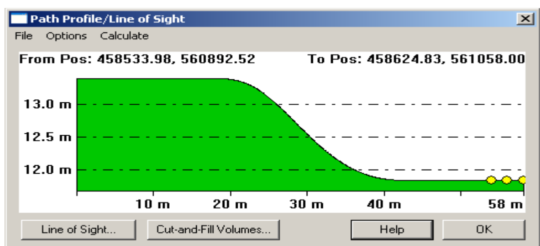


Figure A.23. Smooth gradient cross-section.

This smooth gradient is acceptable to USGS. Note that the bridge has been "cut" in Figure A.22.

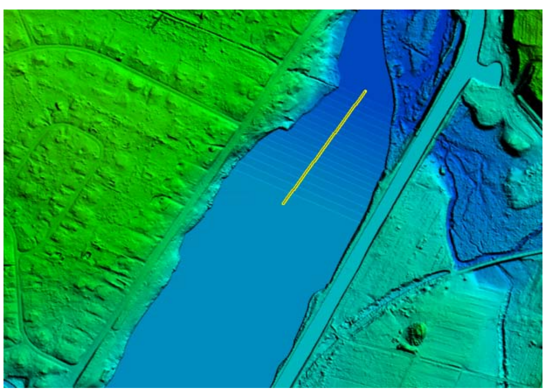


Figure A.24. 10-cm stair-stepped gradient.

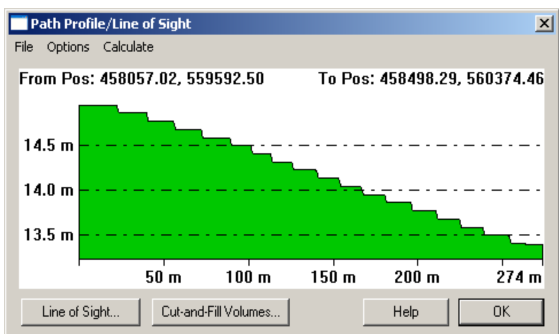


Figure A.25. Stair-stepped (10-cm) cross-section.

A stair-stepped gradient is also acceptable to USGS.

Elevations, orthometric heights and ellipsoid heights

What are elevations? Are they relative to mean sea level? How would a surveyor know where mean sea level is in the middle of Kansas? To answer these questions, we first need to define elevations; orthometric heights; ellipsoid and ellipsoid heights; geoid and geoid heights, and explain how these things are measured or defined.

Ellipsoid – a biaxial ellipsoid of revolution defined by an ellipse with major axis "a" and minor axis "b." The reference ellipsoid used for mapping purposes is a smooth, mathematical surface on which all calculations of latitude and longitude are made (relative to the Equator and Greenwich meridian) and from which ellipsoid heights are determined from GPS surveys. The reference ellipsoid in the U.S. is the Geodetic Reference System of 1980 (GRS80) which is nearly identical to the World Geodetic System of 1984 (WGS84) from which GPS surveys are referenced. See Figure A.26.

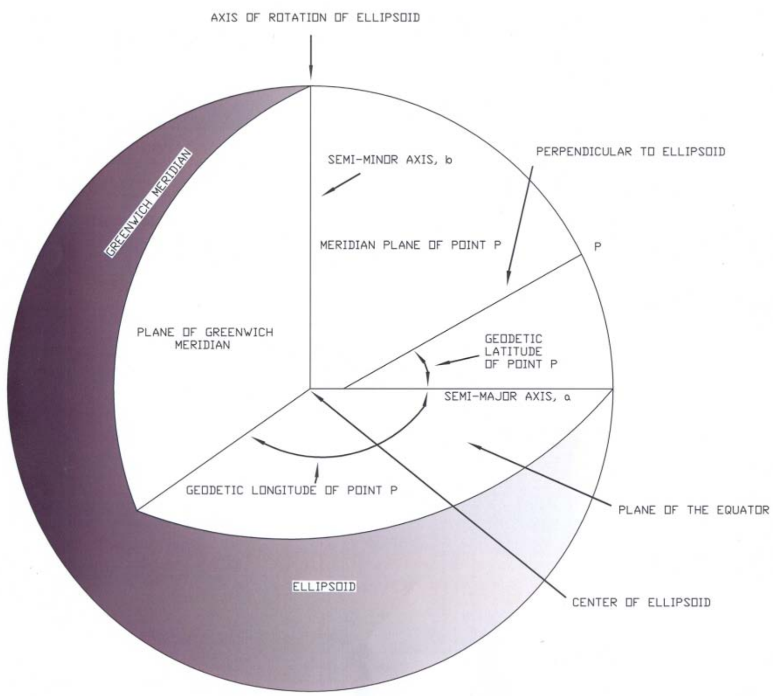


Figure A.26. The mathematical ellipsoid from which geographic coordinates (latitude and longitude) are referenced and from which ellipsoid heights are surveyed by GPS.

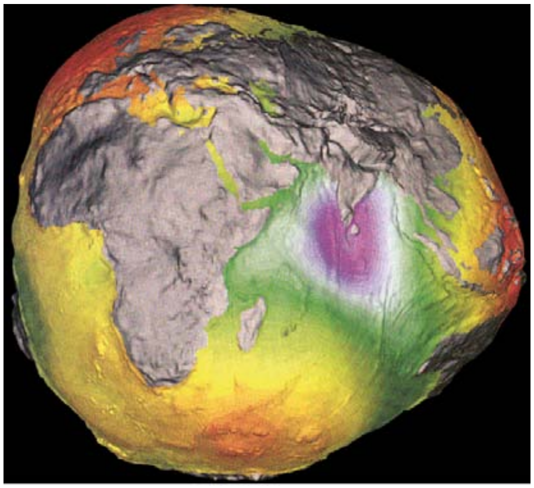


Figure A.27. The gravimetric geoid, from which elevations are determined.

Geoid – that equipotential (level) surface of the earth's gravity field which, on average, coincides with mean sea level in the open undisturbed ocean. In practical terms, the geoid is the imaginary surface where the oceans would seek mean sea level if allowed to continue into all land areas so as to encircle the earth. The geoid undulates up and down with local variations in the mass and density of the earth. The local direction of gravity is always perpendicular to the geoid. Figure A.27 shows the geoid with vertical exaggeration so as to better visualize its departure from a smooth mathematical ellipsoid. Ultimately, gravity measurements determine where mean sea level is in Kansas and elsewhere.

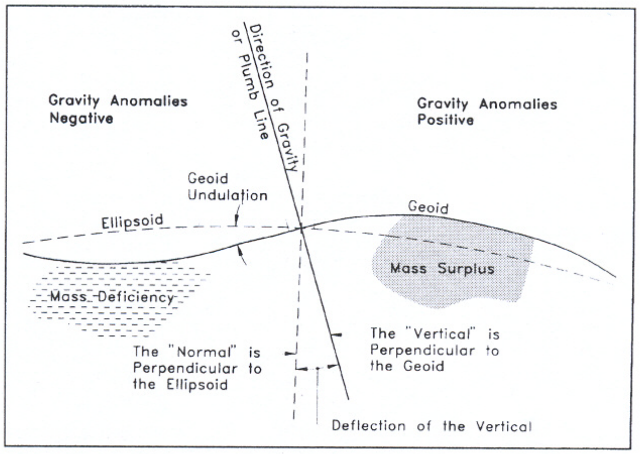


Figure A.28. The undulating geoid, caused by variations in the mass and density of the Earth which in turn causes local changes in the direction of gravity used by conventional surveyors for differential leveling, Total Station surveys, etc.

Figure A.28 shows the undulating geoid relative to the smooth, mathematical ellipsoid, as well as the difference between the normal (perpendicular) to the ellipsoid and the vertical (perpendicular) to the geoid. This difference is called the "deflection of the vertical" and shows why the local direction of gravity would almost never point toward the center of the Earth. Conventional surveys (differential leveling), used to determine elevations, follow the rules of gravity; whereas GPS surveys, used to determine ellipsoid heights, follow the rules of geometry.

Elevation – unofficial name for the distance measured upward along a plumb line between a point being mapped and the geoid. The elevation of a point is essentially the same as its orthometric height, defined as "H" in the equation: H = h – N.

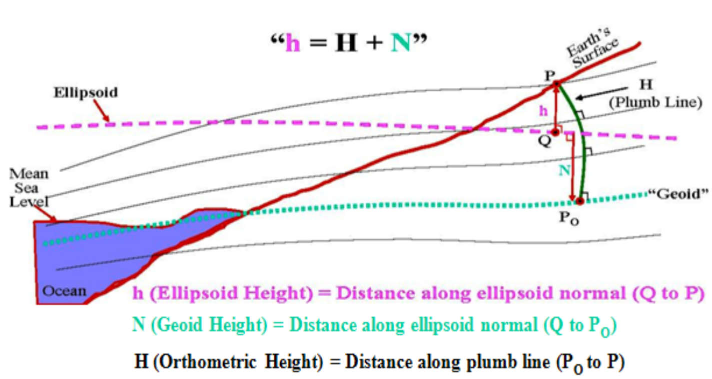


Figure A.29. The relationship between ellipsoid height (h), orthometric height (H) and geoid height (N). Although N has a positive value in most of the world, N has a negative value in the U.S. where the geoid is below the ellipsoid. An "elevation" is an unofficial term for the official "orthometric height."

Orthometric Height – the height of a point being mapped above the geoid as measured along the plumb line between the geoid and a point on the Earth's surface, taken positive upward from the geoid. Defined as "H" in the equation: H = h – N. Orthometric heights are surveyed by conventional survey instruments that establish a horizontal line-of-sight perpendicular to the direction of gravity. Thus, orthometric heights are surveyed by procedures that follow the rules of gravity. In the U.S., N is a negative number, clarifying the formula which otherwise appears reversed.

Ellipsoid Height – the height of a point being mapped above or below the reference ellipsoid, i.e., the distance between a point on the Earth's surface and the ellipsoidal surface, as measured along the normal (perpendicular) to the ellipsoid at the point and taken positive upward from the ellipsoid. Defined as "h" in the equation: h = H + N. Ellipsoid heights are surveyed by ground GPS or airborne GPS, measured above the mathematical ellipsoid, and independent of the Earth's gravity field. Thus, ellipsoid heights are surveyed by procedures that follow the rules of geometry.

Geoid Height – the difference between an ellipsoid height and an orthometric height. Defined as “N” in the equation: N = h – H. See Figure A.30.

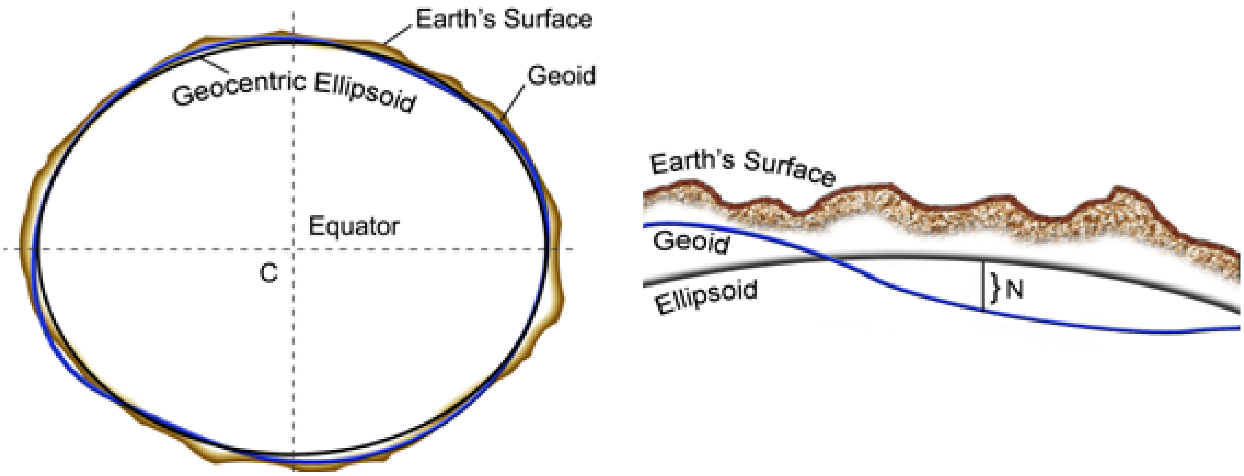


Figure A.30. The figure on the left shows the difference between the mathematical ellipsoid and the gravimetric geoid. The figure on the right shows the geoid height (N) which undulates above and below the ellipsoid. Most computer models of the geoid are actually geoid height models that define the distance of separation (up or down) relative to the ellipsoid. In the U.S., the geoid is below the ellipsoid; thus the value for N is a negative number because the geoid is below the ellipsoid.

Terrain Analyses (Automated and Visual)

While digital elevation models provide the benefit of computer based analysis they also offer the equally important ability to provide an intuitively comprehensible visual display of the terrain characteristics for those who perform manual (visual) analyses of the terrain, vegetation, soils, etc. For diverse NRCS applications, computers offer a dizzying array of options when it comes to viewing surface models and the data derived from them.

The human visual system is the most powerful information-processing mechanism known. Through our sight NRCS specialists can identify patterns and relationships between features and their attributes. Computers enable users to render terrain using both realistic and highly abstract, symbolized, methods. Symbolized representations make it easy for specialists to focus on a particular aspect of the terrain and not hide the patterns they're searching for behind unrelated noise. On the other hand, certain applications benefit from a high degree of realism.

In addition to analysis, visualization of terrain data offers benefits in the form of presentation and communication. People who aren't trained to read maps may have an easier time understanding them if terrain information is included. For example, this can by accomplished by compositing a hillshade image of the surface with relevant thematic information for display on a map. Alternatively, a 3-D perspective with data overlain on top of a terrain model can improve peoples' understanding of the problem. Such as interpreting soils or geology, for example.

Hillshades, described below, and other terrain visualization tools are also used extensively for quality control purposes – helping personnel to perform a "sanity check" on their analyses or those of others. When something is wrong, or appears to be counter-intuitive, 3-D visualizations help to understand the problem or explain it to others.

The graphic at Figure A.31 has been effectively used by the author of this whitepaper to help others understand why the poor DEM for the state of Alaska causes a "logjam" in the production of digital orthophotos and other geospatial products for that state. USGS' DEM for Alaska was produced by digitizing the contours from their paper topographic quad maps produced by USGS in the 1950s, but the pre-GPS technology used to produce these maps back then was so inaccurate that, when combined with poor or non-existent survey control of photo-identifiable ground features, some mountains were mapped up to two miles away from their correct positions. This creates a severe safety hazard for pilots of aircraft who may know exactly where their airplanes are because of today's GPS real-time positioning, but who have inaccurate cockpit displays of the mountain passes they are flying through when forced to rely on inaccurate elevation data produced with 1950's technology. In 2010, digital orthophotos, popular with USDA, cannot be produced for Alaska because airborne or satellite imagery needs to be "draped" over a DEM to produce the orthophotos, as shown at Figure A.32, but the DEM in Alaska is so inaccurate that orthophotos show rivers that climb up and down the mountainsides, as shown at Figure A.31. This problem with the National Elevation Dataset (NED) for Alaska adversely impacts the National Hydrography Dataset (NHD), boundary delineations (based on the positioning of streams, and other geospatial products vital for land management by federal and state agencies, including NRCS. Figure A.31 is a good example of how terrain visualization can be used to understand problems that are difficult to understand by reading words alone.

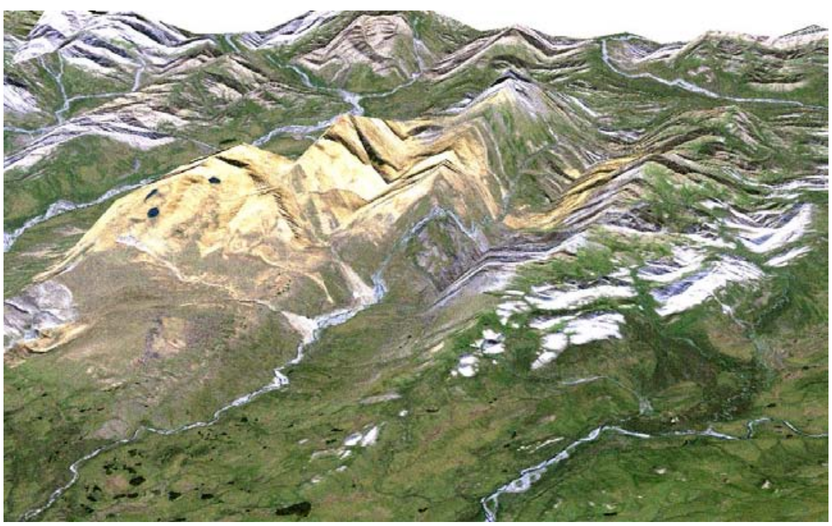


Figure A.31. Orthophotos cannot be produced for Alaska because the DEM in the NED is in error by miles (horizontally) and by over 1,000 ft for some mountains. Rivers appear to climb up and over mountains.

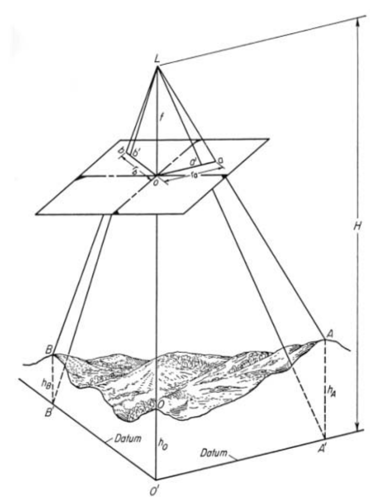


Figure A.32. Orthophotos are produced by "draping" airborne or satellite photos over DEMs.

3-D terrain modeling and simulations are especially important to NRCS engineers, helping them to "see" the results of a simulated dam breach for example, or seeing the results of alternative designs of agricultural terraces, ponds, pipelines and irrigation systems, flood and erosion control structures, etc.

In addition to 3-D terrain visualization and simulation, digital elevation data are very useful when performing spatial analysis. Most information derived from analysis of terrain data is created as input to site selection models in a geographic information system (GIS). Whether the problem is to find the best location to build a farm pond or drainage control structure, or identify the best place to find a particular animal or plant species, the analysis of terrain data will almost always be a key ingredient.

Terrain analysis is frequently performed with DEM derivatives, e.g., analyses of hillshades, slopes, aspects, and curvature, described in the following sections.

Hillshade

Hillshade is a function to create an illuminated representation of the surface to show the terrain and topography. It does this by setting a position for a hypothetical light source and calculating the illumination values of each location. It can greatly enhance the visualization of a surface for analysis or graphical display, and is a very common cartographic technique. Figure A.33 shows an example of a DEM hillshaded by illuminated from an azimuth of 45 degrees and sun angle of 45 degrees. Figure A.34 shows the same surface hillshaded from an azimuth of 70 degrees and sun angle of 70 degrees. Users can vary the azimuth and sun angles to achieve desired visualization effects which become standardized for different applications.

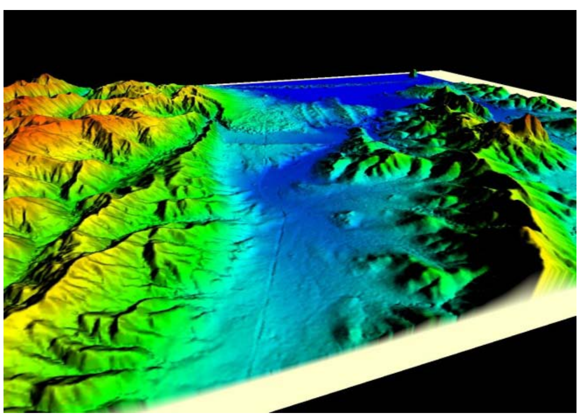


Figure A.33. IFSAR hillshade, sun angle = 45°, azimuth = 45°.

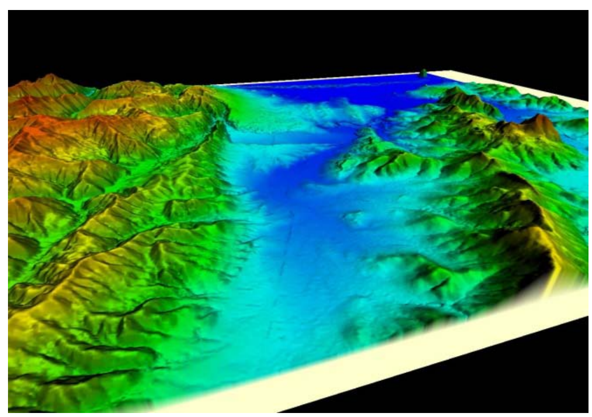


Figure A.34. IFSAR hillshade, sun angle = 70°, azimuth = 70°.

Slope

Slope is a calculation of the maximum rate of change across the surface, either from cell to cell in a gridded surface or of a triangle in a TIN. Every cell in an output grid or triangle in a TIN has a slope value. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. Slope is often calculated as either percent slope or degree of slope.

Slope calculations on terrain models are used in soils mapping; hydrologic and hydraulic (H&H) modeling; soil erosion and flood risk mapping; fire risk analysis; irrigation system planning; wetness index; numerous site selection applications; and easements, for example. Figure A.36 shows a slope map, where green represents the flattest slopes and red represents the steepest slopes, using the same DEM as for the hillshade at Figure A.35. Figure A.36 may appear to be a river, but the distinctive features are actually ridge lines.

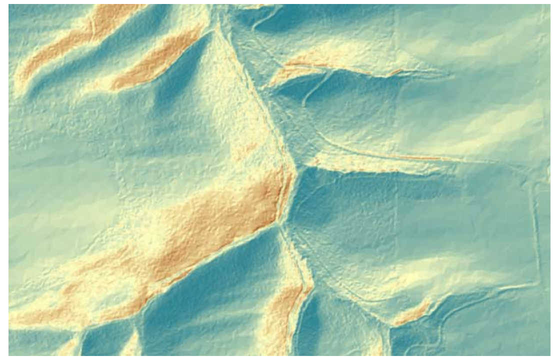


Figure A.35. Hillshade of mountain ridges and roads; compare with slope and aspect maps.

Aspect

Aspect identifies the steepest downslope direction on a surface. It can be thought of as slope direction or the compass direction a hill faces. Aspect is usually measured clockwise in degrees from 0 (due north) to 360 (again due north, coming full circle). The value of each location in an aspect dataset indicates the direction the surface slope faces.

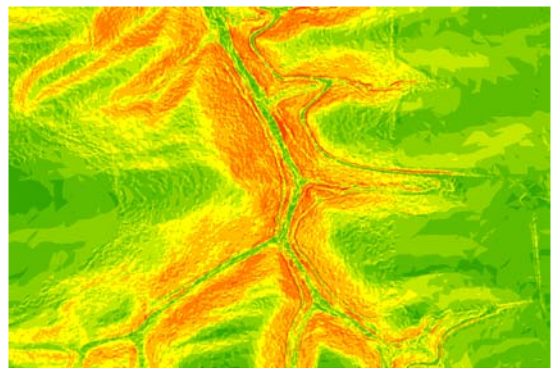


Figure A.36. Slope map of same area. Red is highest slope; green is lowest.

The aspect of a hillside says a lot about what can grow or live somewhere because it determines how much solar energy it receives. This is useful information for soils mapping and for diverse agricultural and forestry applications, depending on the latitude and climate. Figure A.37 shows an aspect map where warm colors (red and pink) face to the south and cool colors (blues) face to the north). Figures A.35, A.36 and A.37 all pertain to the same area that depicts mountain ridges and roads.

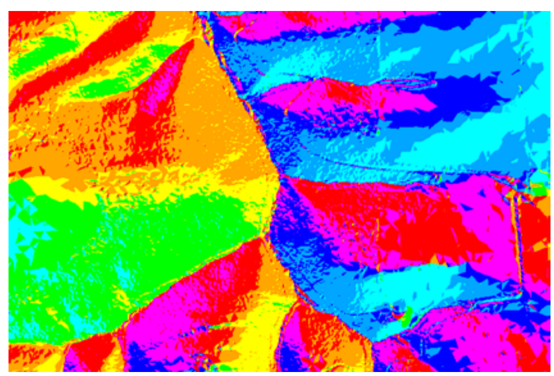


Figure A.37. Aspect map of same area. "Hot" colors face south; "cool" colors face north.

Curvature

Dwain Daniels of NRCS published a paper entitled: "On-Site Verification of Slope Shape: Spatial Analyst Curvature Function" which examines the use of digital elevation data and derivatives by application of the Spatial Analyst curvature function for delineation of separate slope shapes displayed in Figure A.38. Curvature, which is strongly related to the water distribution pattern over and within the landscape, is among the soil forming factors that affect development of soil morphological characteristics and properties over time. The understanding of the way soil properties vary across the landscape as a result of slope, aspect, curvature and other factors is known as the soil-landscape model; its comprehension by the soil scientist enables the prediction of soil occurrence from landscape position. The more thoroughly the soil-landscape model is understood, the more accurate and useful a soil map is for interpretation and use. The derivative products (slope, aspect, curvature) of an accurate DEM provide valuable tools for a soil scientist to use in discerning a preliminary outline of the landscape configuration and in quantifying existing soil map unit delineation composition.

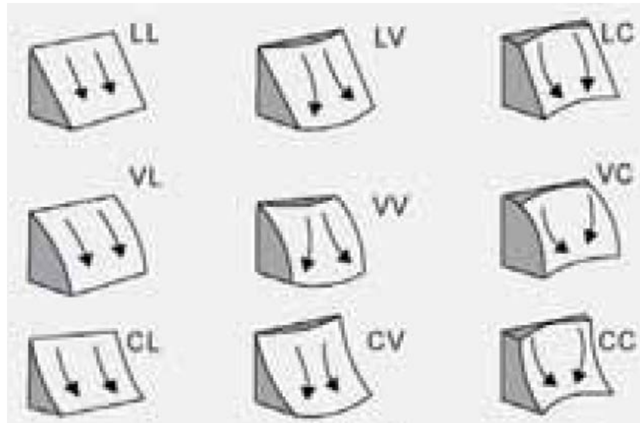


Figure A.38. Slope shape is described in two directions: up-and-down slope (perpendicular to the contour) and across slope (along the horizontal contour); e.g., Linear, Convex or LV. L = Linear; V = Convex; C = Concave. The arrows show the surface flow pathway.

In Appendix G, Figure G.6 shows "planform curvature;" Figure G.7 shows "profile curvature;" and Figure G.8 shows "tangential curvature."

DEM Technologies

Stereo Imagery and Photogrammetry

Photogrammetry is an art, a science, and a proven technology that enables 3-D mapping of the terrain to be made from 2-D measurements of stereo images with contour interval accuracy as small as 1 foot, or even down to 6 inches. Aerial photogrammetry uses stereo aerial photographs or stereo digital images to create topographic maps of features visible on the imagery and to determine the relative location of points, lines and areas for determination of distances, angles, areas, volumes, elevations, sizes and shapes of mapped features.

Stereo photographs or stereo images are those taken of the same area on the ground but viewed from two different perspectives. As shown at Figure A.39, conventional film cameras and digital frame cameras are commonly flown with each image having a 60% overlap with the preceding and subsequent images; this enables 60% of each photograph to overlap the same area shown on the preceding and subsequent photographs, and 10% of each photograph to appear on three successive photographs, called the triple-overlap area. The aircraft flies at a pre-planned elevation (H') above mean terrain in order to obtain the desired scale of photography. The base (B) between exposure stations (L_1 and L_2) is planned to achieve≥60% overlap between exposures, allowing the terrain in the hashed area to be mapped in stereo. Stereo photogrammetry converts images from a perspective projection into an orthographic projection, as though looking straight down from infinity. The larger the angle ϕ in Figure A.39, the more accurate are the mapped elevations.

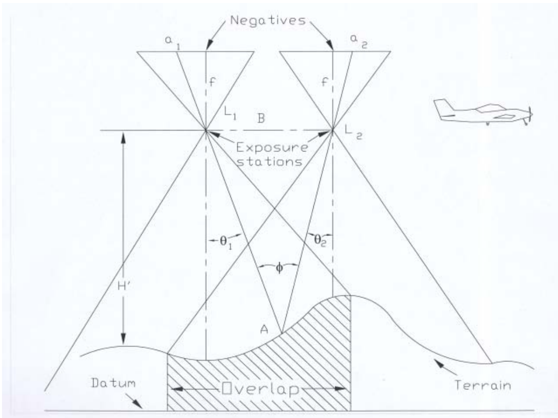


Figure A.39. Stereo imagery acquired by conventional film cameras and digital frame mapping cameras, e.g., DMC and UltraCam, viewing the same area from two perspectives.

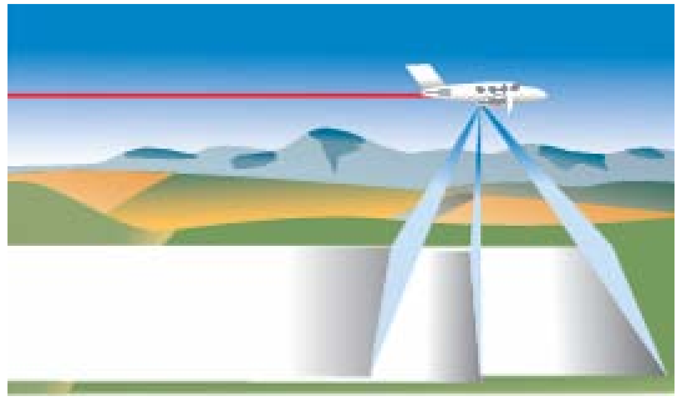


Figure A.40. Stereo imagery acquired by digital line scanners, commonly called "pushbroom" sensors, that acquire a single line of imagery looking forward, downward, and backward, allowing choices in which stereo pairs to use with different incidence angles.

As shown at Figure A.40, pushbroom sensors create stereo images by scanning the terrain looking forward, downward, and backward so that all areas are imaged from three perspectives. With stereoscopic viewing, much greater depth perception can be obtained. Stereoscopic viewing enables the formation of a 3-dimensional stereomodel for viewing a pair of overlapping images, making accurate 3-D measurements and mapping elevations in addition to planimetric detail.

Digital elevation data are produced by using both manual and automated techniques. As shown at Figure A.41, manual photogrammetry is used for traditional contouring, where human judgment is used to select stereo points on the bare-earth terrain surface only and to artistically compile contours to conform to cartographic convention; manual photogrammetry is also used for generation of breaklines where a human operator can visually interpret the edges being digitized. The operator is wearing polarized glasses that enable him to see in 3-D. As shown at Figure A.42, automated image correlation techniques are used to produce mass points at set interval of x and y; because automated image correlation matches pixels from the top reflective surface, these mass points initially form a digital surface model (DSM). Semi-automated techniques are then used to filter these points to classify only those points shown in green as part of a bare-earth DTM, void of trees and buildings.

Figure A.41. Manual photogrammetry where human judgment is used for stereo compilation of breaklines and contours. The operator is wearing polarized glasses for 3D viewing. This same technique is used with lidargrammetry.

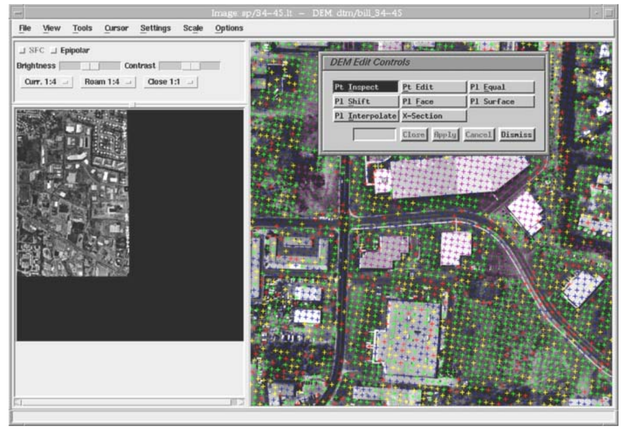


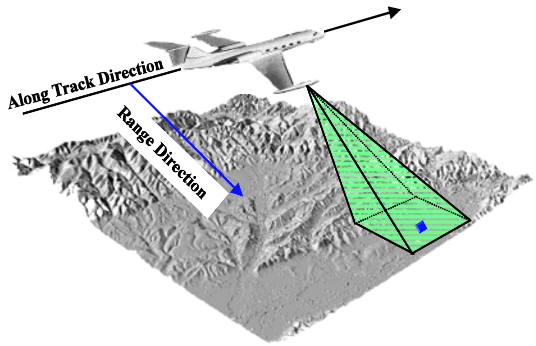
Figure A.42. Automated photogrammetry where computer processing correlates points in stereo; the initial DSM is than filtered to retain only those points in green for inclusion in a bare-earth DTM.

A large percentage of photogrammetric applications have traditionally pertained to topographic mapping, at various scales, of paper topographic maps. However, since the development of digital photogrammetric processes and digital cameras, two digital photogrammetric products, *digital orthophotos* and *digital elevation models*, are now often used in combination to replace traditional topographic maps. An orthophoto is an aerial photograph that has distortions removed, has a uniform scale throughout, and has the metric properties of a planimetric map; but unlike planimetric maps that show features by using lines and symbols, orthophotos show the actual images of features, making them easier to interpret. A digital elevation model (DEM) has been previously described throughout this Appendix. Orthophotos and DEMs are widely used in all fields where maps are used, but because they are in digital form, they are ideal for use for modern geographic information system (GIS) applications.

In summary, photogrammetry is a proven and well-understood technology. When edges are visible on stereo images, photogrammetry is ideal for compilation of 3-D breaklines. Photogrammetry is the least expensive alternative for small projects of a few square miles. The major disadvantage is in forested areas where stereo images normally cannot see the bare earth terrain from two perspectives.

Interferometric Synthetic Aperture Radar (IFSAR)

Interferometric Synthetic Aperture Radar (IFSAR technology is newer than photogrammetry and more difficult to explain. Readers wishing to understand more about the technical details are encouraged to read Chapter 6, IFSAR, of "Digital Elevation Model Technologies and Applications: The DEM Users Manual," 2nd edition, published by ASPRS in 2007. In addition to the Shuttle Radar Topography Mission (SRTM) in 2000 (~100 ft contour accuracy), there are several satellites that collect elevation data from radar, e.g., Radarsat and TerraSar-X (~50-80 ft contour accuracy). Figures A.43 and A.44 illustrate the acquisition geometry of the two airborne IFSAR systems used in the U.S. (~10-20 ft contour accuracy).



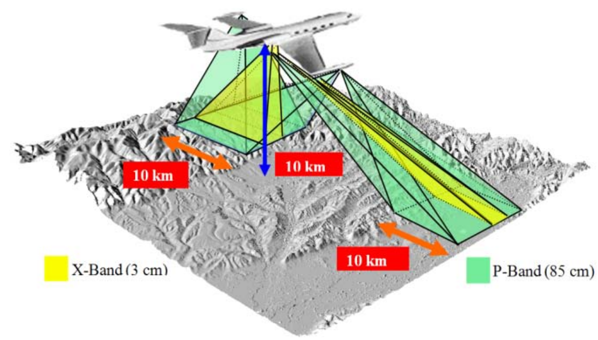


Figure A.43. Intermap's STAR systems utilize X-band radar that looks to only one side of the aircraft. Intermap has used their four STAR systems to produce NEXTMap products for the U.S., Europe and Great Britain. In the U.S., only Alaska has not been mapped with this technology.

Figure A.44. Fugro EarthData's GeoSAR system utilizes both X-band and P-band radar that looks to both sides of the aircraft. This more-expensive system is largely used overseas by DoD to support military operations in areas of dense vegetation and/or rugged terrain.

Both of these airborne IFSAR sensors deliver three products illustrated at Figures A.45, A.46 and A.47. Both firms produce Digital Surface Models (DSMs) from their X-band data which maps the top reflective surfaces. Fugro produces a Digital Terrain Model (DTM) from GeoSAR's P-band data (which penetrates vegetation to some degree) whereas Intermap produces a DTM by processing of the STAR X-band data with techniques similar to those used with photogrammetry and LiDAR. Both firms produce Ortho-rectified Radar Imagery (ORI) that looks similar to black-and-white imagery; Intermap's ORI has 62.5-cm pixel resolution, whereas Fugro's has 3-meter pixel resolution.

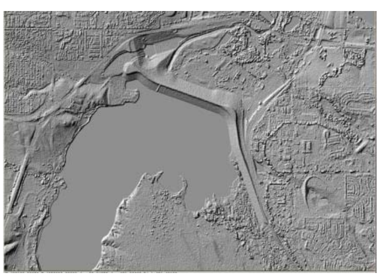


Figure A.45. DSMs are similar from Intermap and Fugro mapping top reflective surfaces.

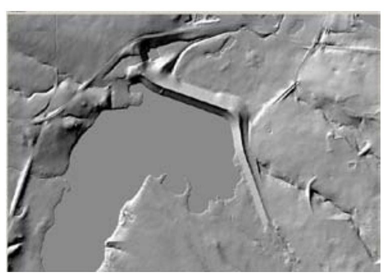


Figure A.46. DTMs are produced differently by Intermap and Fugro for building/vegetation removal.

Figure A.47. ORIs from Intermap and Fugro have different pixel size but clearly map water features.

A technical advantage of IFSAR is that it is an all-weather system and maps through clouds. A technical disadvantage of IFSAR is that it can have data voids from layover, shadow, and foreshortening, illustrated at Figure A.48; such voids are filled by other data from ancillary sources, such as the National Elevation Dataset (NED). Nevertheless, IFSAR is the lowest cost solution for delivery of DEMs with approximately 10-foot contour accuracy. Such DEMs can be licensed from Intermap today from their NEXTMap USA data, available nationwide for 49 of the 50 states (all except Alaska). It is not public domain data and is not currently part of the NED.

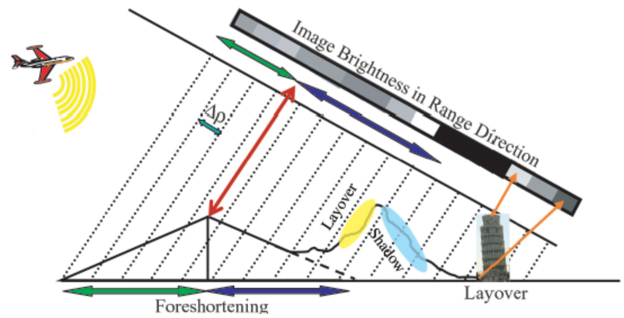


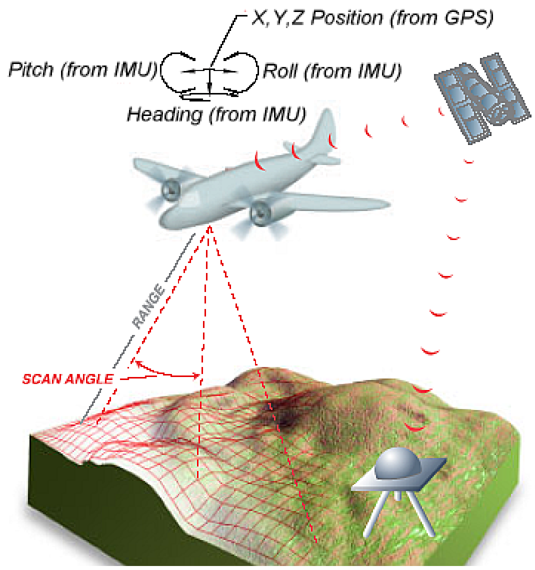
Figure A.48. Both satellite and airborne IFSAR can have data voids caused by foreshortening, layover and shadow. Such voids must be filled by other means.

LiDAR and Lidargrammetry

Light Detection and Ranging (LiDAR) emits thousands of laser pulses per second to accurately map elevations with 1- or 2-foot contour accuracy. For greater details, see Chapter 7 in "Digital Elevation Model Technologies and Applications: The DEM Users Manual," published in 2007 by ASPRS. Figure A.49 shows a cartoon depiction of a LiDAR system that relies on four basic system components for accurate mapping of hundreds of thousands of mass points per second:

- Airborne GPS is needed to determine the x, y, z coordinates of the moving sensor in the air, surveyed relative to one or more differential GPS base stations. This establishes the origin of each of the thousands of laser pulses emitted each second.
- The inertial measurement unit (IMU) directly measures the roll, pitch and heading of the aircraft, establishing the angular orientation of the sensor about the x, y and z axes in flight.
- The LiDAR sensor itself measures the scan angle of the laser pulses. Combined with IMU data, this establishes the angular orientation of each of the thousands of pulses emitted each second.
- The LiDAR sensor also measures the time necessary for each emitted pulse to reflect off the ground (or features thereon) and return to the sensor. Time translates into distance measured between the aircraft and each mass point being surveyed.

Airborne LiDAR sensors currently emit up to 200,000 laser pulses per second in some form of scanning array, most commonly a zig-zag pattern. The scan angle, flying height, and pulse repetition rate determine the nominal point spacing in the cross-flight direction, whereas the scan rate, flying height, and the airspeed determine the nominal point spacing in the in-flight direction. Each laser pulse has a pulse width (typically about 1 meter in diameter) and a pulse length (equivalent to the short time lapse between the time the laser pulses are turned on and off again); therefore, each laser pulse actually is like a cylinder of light with diameter and length. Each laser pulse may have multiple returns from features "hit" at different elevations, creating a "point cloud" of elevation points including treetop and rooftop elevations, intermediate tree branches and understory, as well as elevations of bare-earth mass points. Figure A.50 shows examples of LiDAR point clouds in trees and those on the ground at the base of the trees. LiDAR last returns are used for DTMs, but not all last returns reach the ground.



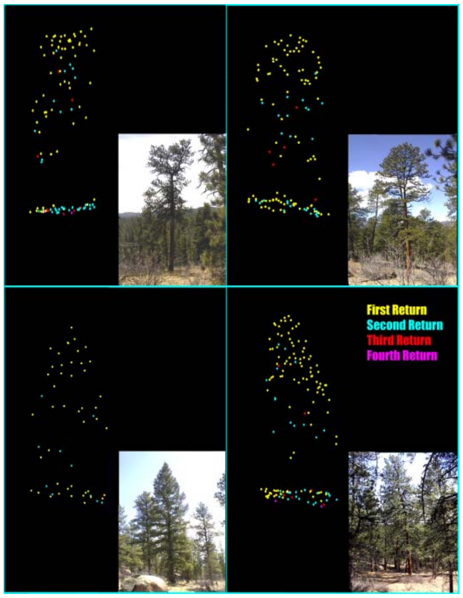


Figure A.49. LiDAR system components necessary to determine the position and orientation of the sensor, plus the scan angle and range to each pulse.

Figure A.50. LiDAR point clouds as mapped in trees with 1st, 2nd, 3rd and 4th pulses. The last pulse does not always reach the ground in dense vegetation.

Whereas IFSAR produces ortho-rectified radar images (ORIs), LiDAR produces intensity values that are valuable for classification purposes. By reviewing the intensity returns, it is possible to distinguish between different objects and general vegetation cover. As a general rule, objects with high reflectivity of visual light, such as a metal roof, show a higher return energy than objects such as newly paved, black-tarred roadways. Figure A.51 shows a first-return LiDAR dataset of Baltimore Harbor; note the ships at dock in the harbor at "3 o'clock." Figure A.52 shows the LiDAR intensity returns for this same scene; at full scale, it is easier to see the paint stripes on the football field from intensity returns than it is to clearly distinguish the water boundary in Baltimore Harbor.

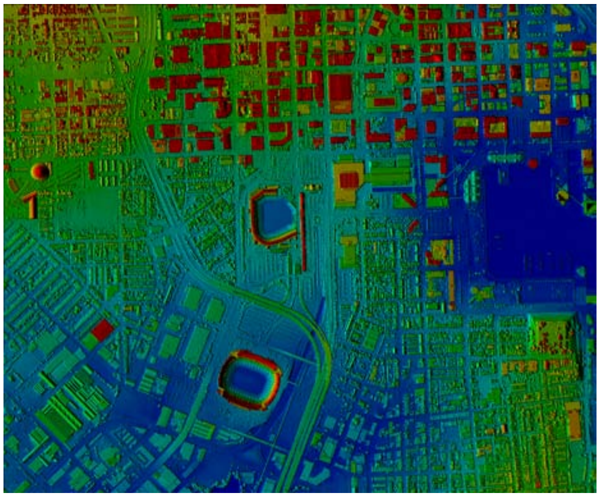


Figure A.51. Baltimore Harbor 1st return LiDAR.

Figure A.52. Baltimore Harbor intensity returns.

Lidargrammetry is now emerging as a popular tool for production of 3-D breaklines from LiDAR. With LiDAR emerging as the most popular technology for generating high-resolution, high accuracy 3D terrain models of the earth, lidargrammetry techniques have been developed (by GeoCue) to extract greater information from the basic LiDAR data sets now available from commercial vendors. Lidargrammetry is somewhat similar in conception to radargrammetry developed by Intermap Technologies and essentially employs similar software to produce a 3D image by creating overlapping stereo pairs from a single radar "intensity" image and the 3D information from the direct elevation and position measurements. The basic functionality to perform radargrammetry or lidargrammetry is found in most softcopy photogrammetric software, e.g., Socet Set.

In simple terms, a photogrammetric software package utilizes the reconstructed rays from digital imagery (including digitized film photographs) to produce a 3D image which can be measured at the intersection of the light rays forming that image. The photogrammetrist can see the images in 3D and thus the changes in elevation. In lidargrammetry, theoretically the same algorithms are used in reverse. The input now, though, is one image of the ground from the amplitude of the LiDAR intensity return signal plus its elevation data. Therefore two pseudo images called a pseudo stereo pair (PSP) can be constructed which allow a photogrammetric system operator to "see" in 3D and use this facility to better determine the location of ground features. Although other applications are expected to emerge, lidargrammetry is largely used today for stereo compilation of 3D breaklines from LiDAR stereo images for which elevations can be exaggerated so as to clearly distinguish small changes in elevation. Photogrammetric software often includes a z-lock function that enables the shorelines of lakes and reservoirs to be perfectly flat and level.

In summary, LiDAR has emerged as the technology of choice in digital elevation mapping when accuracy requirements are for 1-foot or 2-foot contour accuracy, as specified by the majority of NRCS personnel who responded to the questionnaire at Appendix B. LiDAR is clearly superior to either photogrammetry or IFSAR in mapping the bare-earth terrain in forests or areas of dense vegetation, as at Figures A.9 and A.10. Furthermore, LiDAR is superior for virtually all of the DEM applications identified in the NRCS survey questionnaire. High resolution digital elevation data from LiDAR, combined with digital orthophotos, comprise the two geospatial data sets of highest value to NRCS users in all applications.

DEM Accuracy Standards and Guidelines

Chapter 3 of "Digital Elevation Model Technologies and Applications: The DEM Users Manual" describes the various references that pertain to DEM accuracy standards and guidelines, to include the following:

- National Map Accuracy Standards (NMAS), developed in 1947 for paper topographic maps. The NMAS reported both horizontal and vertical data accuracy at the 90% confidence level and did not assume that errors followed a normal error distribution. The horizontal standard was called the Circular Map Accuracy Standard (CMAS), reported as Circular Error at the 90% confidence level (CE90); and the vertical standard was called the Vertical Map Accuracy Standard (VMAS), reported as Linear Error at the 90% confidence level (LE90).

- National Standard for Spatial Data Accuracy (NSSDA), developed in 1988 by the Federal Geographic Data Committee (FGDC) for accuracy reporting of all digital geospatial data. The NSSDA reports both horizontal and vertical data accuracy at the 95% confidence level and assumes that all errors follow a normal error distribution. The horizontal standard is called $Accuracy_r$ (horizontal radial accuracy at the 95% confidence level), computed statistically as a function of root mean square errors ($RMSE_x$, $RMSE_y$, and $RMSE_r$). The vertical standard is called $Accuracy_z$ (vertical accuracy at the 95% confidence level), computed statistically as a function of $RMSE_z$. $Accuracy_z = RMSE_z \times 1.9600$.
- *Guidance for Aerial Mapping and Surveying*, developed in 2003 to explain FEMA's needs for elevation data (typically 2-foot contour accuracy) for floodplain mapping and specifying FEMA requirements for accuracy testing in 3-5 major land cover categories representative of the floodplains being mapped. For the past decade, these FEMA guidelines have remained the *de facto* standard for LiDAR.
- *Guidelines for Digital Elevation Data*, published in 2004 by the National Digital Elevation Program (NDEP) to provide alternatives for testing and reporting of elevation data, especially when errors do not follow a normal error distribution, as with LiDAR. The NDEP defined three new terms for vertical accuracy testing and reporting at the 95% confidence level: Fundamental Vertical Accuracy (FVA) tested only in open (non-vegetated) terrain, Supplemental Vertical Accuracy (SVA) tested in multiple land cover categories, and Consolidated Vertical Accuracy (CVA) tested in all land cover categories combined.
- *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data,* published in 2004 by the American Society for Photogrammetry and Remote Sensing, to adopt the NDEP guidelines and provide additional guidance for those who test and report the accuracy of LiDAR data, with priority given to the FVA statistic.

Table A.1 compares the NMAS and NSSDA standards relative to equivalent contour interval accuracy. With this table, users can compare the different terminologies (LE90, Accuracyz, RMSEz, FVA, SVA or CVA) and relate them back to "What is that in terms of contour interval?"

Table A.1. Comparison of Accuracy Standards in Terms of Equivalent Contour Intervals

NMAS Equivalent Contour Interval	**NMAS** VMAS 90 percent confidence level (LE90)	**NSSDA** $RMSE_z$	**NSSDA** $Accuracy_z$, 95 percent confidence level, also FVA, SVA, CVA
1 ft	0.5 ft	0.30 ft or 9.25 cm	0.60 ft or 18.2 cm
2 ft	1.0 ft	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm
4 ft	2.0 ft	1.22 ft or 37.0 cm	2.38 ft or 72.6 cm
5 ft	2.5 ft	1.52 ft or 46.3 cm	2.98 ft or 90.8 cm
10 ft	5.0 ft	3.04 ft or 92.7 cm	5.96 ft or 181.6 cm
20 ft	10.0 ft	6.08 ft or 185.3 cm	11.92 ft or 363.2 cm

Appendix B – NRCS DEM Questionnaire and Responses

1. **What organization do you represent?**

Organization	Responses
NRCS Headquarters	3
National Cartography and Geospatial Center (NCGC)	3
Conservation Engineering Division (CED)	4
Conservation Planning Division (CPD)	2
Easement Programs Division (EPD)	1
Ecological Site Division (ESD)	2
Resources Inventory and Assessment Division (RIAD)	1
Soil Survey Division (SSD)	15
Other National Center	6
State Office	57
GIS Specialist	50
State Soil Scientist	10
State Engineer	12
NRCS Liaison	1
Other	70

2. **If State Office, please list State.**

Replies received from 47 states; however, because respondents were allowed to remain anonymous, some representatives from the missing states participated in the three workshops and stated that they had responded. Thus, representatives from all states were included in the survey.

3. **If other National Center, please specify.**

ENTSC (East National Technology Support Center) in Greensboro, NC

NGDC (National Geospatial Development Center) in Morgantown, WV

NSSC (National Soil Survey Center) in Lincoln, NE

NTSC (National Technology Support Centers) in Greensboro, NC (East); Fort Worth, TX (Central); and Portland, OR (West)

NWCC (National Water and Climate Center) in Portland, OR

NWMC (National Water Management Center) in Little Rock, AR

4. **Contact information (optional).**

A total of 117 provided contact information.

5. **What is your preferred source of elevation data?**

Source of Elevation Data	Responses
Optical imagery/photogrammetry	4
Interferometric Synthetic Aperture Radar (IFSAR)	4
Light Detection and Ranging (LiDAR)	94
No preference; whatever delivers data most cost-effectively	45
Other	5

6. **Does your organization create elevation products, e.g., DEM's, TIN's, hillshades, slope maps, etc. from source data such as LiDAR or IFSAR?**

Answer	Responses
Yes	126
No	23

7. **Do you also need bathymetric data showing elevations of the terrain beneath water surfaces?**

Answer	Responses
Yes	63
No	85

8. **Please summarize the user applications and program (soils, engineering, conservation planning, easements, wetlands, precision agriculture, etc.) for which you require High Resolution Elevation Data.**

Please see Appendix C for detailed responses to this question

9. **Please summarize the project areas (geographic extent) for which your elevation data requirements apply. Specify the state, county, major land resource area, watershed, site, etc.**

Responses included nationwide; statewide, countywide and regional areas; and individual watersheds, floodplains and MLRAs. Appendix C includes specifics when provided by respondents.

10. Which elevation surface do you need for your Digital Elevation Model (DEM)?

Answer	Responses
Digital Surface Model (DSM) or top reflective surface	0
Digital Terrain Model (DTM) of bare earth terrain	81
Both DSM and DTM	67

11. Which elevation data type do you need?

Answer	Responses
Orthometric heights	33
Ellipsoid heights	5
Both orthometric and ellipsoid heights	25
Don't know	84

12. Which elevation model types do you need? Choose all that apply.

Answer	Responses
Mass points	59
Breaklines	80
TINs	60
ESRI Terrains	63
Contour lines	109
Gridded DEM with uniform point spacing	113
Other	7

Note: Contours are used for human analysis and interpretation. All other elevation model types listed are used for computer modeling and automated forms of analyses. The responses to question 12 indicate that approximately half the respondents still rely upon less-efficient manual processes rather than more-efficient automated processes. It is possible that some users still prefer manual processes, but it is more likely that they have not had the digital elevation data, hardware, software and training necessary to experience the benefits of automation using digital elevation data.

13. If you need a gridded DEM, what uniform post spacing do you need?

Answer	Responses
1 meter	93
2 meter	46

5 meter	50
10 meter	16
20 meter	3
1/9th arc second (~ 3 meter)	15
1/3rd arc second (~ 10 meter)	5
1 arc second (~ 30 meter)	4
Other (please specify)	13

Other: requirements vary with scope and resolution of each project.

14. What DEM file formats do you require? (List all that apply)

Answer	Responses
LAS	45
ASCII XYZ	49
GeoTiff	32
ESRI Grid	102
.IMG	24
CAD (DSF or DGN)	49
Other (please specify)	6

Other: ESRI File and Enterprise Geodatabase Raster Dataset

15. What are your requirements for elevation data usability? (List all that apply)

Answer	Responses
FGDC-compliant metadata	76
Free from artifacts, buildings, trees	85
Free from “corn-rows” that exceed 20 cm	46
Smooth, continuous surface	73
No visible seamlines	86
No “over-smoothing” of data	72
No data voids >1 acre, except where data classified as non-terrain (e.g., water, buildings, towers, vegetation, noise, etc.)	79
Other (please specify)	11

Other: depends on the nature of the project; seamless; no noise; as close to reality that can be delivered; areas of higher uncertainty identified.

16. What are your surface treatment requirements?

Answer	Responses
a. Hydro-enforced so that lakes are flat, rivers are flat bank-to-bank and flow downstream, major bridges/culverts are "cut" to show water flows beneath, and depressions (sinks) are not filled. (Required for hydrologic analysis)	75
b. NED-type DEMs where lakes are flat, rivers are flat bank-to-bank and flow downstream, elevations on major bridges/culverts are retained and not "cut," and depressions (sinks) are not filled.	37
c. Same as "a" except that depressions (sinks) are filled.	12
d. Same as "b" except that depressions (sinks) are filled.	4

17. Must all NRCS elevation data be standard, or can variable elevation datasets be acceptable?

Answer	Responses
All elevation data produced for NRCS should meet a common standard for accuracy, surface treatment, horizontal and vertical datums, coordinate systems, units, file formats, etc.	68
Variable elevation datasets are acceptable, assuming the metadata clearly explains all relevant information necessary for data transformations, if required.	71

18. How often do you need your elevation data to be updated?

Answer	Responses
Annually	6
Biennially	10
Every 5 years	47
Every 10 years	24
Every 20 years	7
Variable	38
Other (please specify)	11

Other: Some parts of the country would need higher rate of update

19. Do you have (or had) any requests for elevation data to support precision agriculture in your state?

Answer	Responses
Yes	23
No	94

20. Are there any precision agriculture user/technology groups in your state?

Answer	Responses
Yes	63
No	42

21. Are you an active member in any precision agriculture user/technology groups in your state?

Answer	Responses
Yes	3
No	119

22. Have you ever attended the InfoAg conference for precision agriculture?

Answer	Responses
Yes	7
No	117

23. Have you ever been contacted by industry companies about precision agriculture?

Answer	Responses
Yes	14
No	106

24. Does anyone at NRCS in your state act as a point of contact for precision agriculture questions?

Answer	Responses
Yes	35
No	63

25. Do you know of any success stories using LiDAR for precision agriculture in your state?

Answer	Responses
Yes	5
No	108

26. Please explain any “yes” answers to previous agriculture questions.

- Farmers in the area are using GPS guided equipment (Texas, Indiana and Washington)
- Private consulting firms use Precision Ag (Colorado)
- We have been contacted by Precision Ag companies in regards to nutrient and pest plans (Minnesota)
- We have periodic Precision Ag. Workshops in our state (South Dakota)
- I have attended conservation district meetings concerning precision agriculture, and met with industry equipment providers about precision agriculture needs from our agency (data and data distribution) to support the customer (Region 8 MRLA Office, all of Arizona, parts of NM, UT, TX).
- Farmers within the Mississippi Delta are interested in applying Precision Ag. Individuals have asked about the availability of elevation data (Mississippi).
- There are “high yield” groups in North Dakota that focus on Precision Agriculture.
- I have been contacted by software vendors for data; have participated in some Precision Ag. research efforts (Illinois)
- I‘ve discussed utilization of Prec. Ag. at several conferences (Texas)
- I work with University of Kentucky and pilot producers with GPS/Prec.Ag.
- Our State Agronomists serve as Precision Agriculture POCs (Montana, Florida, Louisiana, and Washington)
- University staff only (Nebraska, New York)
- I’ve been involved with discussions with Penn State crops and soils on how to best research and disseminate prescription farming in PA.
- Included within our Farm Bill program cost share (Maryland)
- The State GIS Coordinator (Wyoming) handles Precision Ag. requests; Precision Ag. is becoming more common in Wyoming.
- Tim Carney, ASTC for Programs (Montezuma County, Colorado)
- There is a consortium of groups organized through Montana State University which focuses on remote sensing data and precision agriculture. I think that most people don't know there is LIDAR data for an area and so they don't request assistance from NRCS concerning this type of data or application. In addition, the NRCS as an agency doesn't have much if any expertise in working with this kind of data at the field office level. Soil survey personnel, understand the data a little better because we use DEM data more and really see the value of having higher resolution elevation data.

27. How do District Conservations handle questions from land owners about precision agriculture?

- Many answered "I don't know"
- Refer to State Agronomist and/or other POCs mentioned previously
- Refer to area Engineer
- Refer to university extension service
- Refer to State Resource Conservationist
- Refer to private vendors

28. What vertical accuracy do you require for your elevation data?

Answer	Responses
1-ft contour accuracy (6" vertical accuracy at 90% confidence level)	63
2-ft contour accuracy (1' vertical accuracy at 90% confidence level)	40
4-ft contour accuracy (2' vertical accuracy at 90% confidence level)	3
5-ft contour accuracy (2.5' vertical accuracy at 90% confidence level)	6
10-ft contour accuracy (5' vertical accuracy at 90% confidence level)	3
20-ft contour accuracy (10' vertical accuracy at 90% confidence level)	1
Don't know	9
Other (please specify)	14

Other:

- Varies with purpose and terrain
- Varies with application generally 1- to 2-ft contour accuracy
- 1-ft is desired; best available is acceptable
- My detail work justifies 1-ft, I can work with 5-and 10-ft contours for parts of or all of some job types, but at the structural or earth moving locations of a project I can justify the 1-ft accuracy
- Depends upon what is being done - planning or engineering
- Relative accuracy and correct surface shape is more important for terrain analysis
- 1' or 2' depending on the type of project
- Not sure, but highest accuracy available for money. For soil survey (?), but engineering needs 1-ft and we should only buy it once.
- 0.5 ft.; depends on the project, but usually need high accuracy - better than 6" vertical accuracy and good RMSE
- 15 cm RMSE
- 2 cm point to point on hard open surfaces
- Variable but generally must be at least 0.5 feet or tighter.

- 0.1 feet would be best for our engineering needs. [Note: not achievable from airborne methods. Terrestrial-based LiDAR can deliver this accuracy, but very expensive.]

29. What horizontal accuracy do you require for your elevation data?

Answer	Responses
Map scale of 1”=100’ (CE90 3.33’ horizontal accuracy at 90% conf level)	65
Map scale of 1”=200’ (CE90 6.67’ horizontal accuracy at 90% conf level)	22
Map scale of 1”=400’ (CE90 13.3’ horizontal accuracy at 90% conf level)	5
Map scale of 1”=500’ (CE90 16.7’ horizontal accuracy at 90% conf level)	7
Map scale of 1”=1000’ (CE90 33.3’ horizontal accuracy at 90% conf level)	9
Map scale of 1”=2000’ (CE90 40.0’ horizontal accuracy at 90% conf level)	3
Don’t know	18
Other (please specify)	9

Other: Variable

30. What are your requirements for vertical accuracy reporting, either of which would be consistent with reporting requirements of the National Standard for Spatial Data Accuracy?

Answer	Responses
Vertical accuracy must be tested and reported to prove vertical accuracy requirements have been met	91
Without testing, use the “compiled to meet” vertical accuracy statement	25

31. What are your requirements for horizontal accuracy reporting, either of which would be consistent with reporting requirements of the National Standard for Spatial Data Accuracy?

Answer	Responses
Horizontal accuracy must be tested and reported to prove vertical accuracy requirements have been met	83
Without testing, use the “compiled to meet” horizontal accuracy statement	33

32. What horizontal datum do you require?

Answer	Responses
North American Datum of 1983 (NAD 83)	135
North American Datum of 1927 (NAD 27)	2
Other (please specify)	2

Other: Local horizontal datums.

33. What vertical datum do you require?

Answer	Responses
North American Vertical Datum of 1988 (NAVD 88)	112
National Geodetic Vertical Datum of 1929 (NGVD 29)	3
International Great Lakes Datum of 1985 (IGLD 85)	1
Other (please specify)	5

Other: Local vertical datums.

34. What coordinate system do you require?

Answer	Responses
Geographic	18
Universal Transverse Mercator (UTM)	116
State Plane	33
Other (please specify)	11

Other:

- Near zone breaks UTM or SP may be preferred;
- Albers Equal Area
- Current soil inventory activities require UTM NAD 83, XYZ meters
- Prefer UTM, 2nd choice KY Single Zone (FIPS 1600)
- County coordinate system
- Elevation data in geographic are difficult to use, derivatives cannot be calculated without re-projecting, the math doesn't work, degrees/meters=??
- Albers Equal Area USGS projection in ArcGIS for making large area assessments like MLRA regions

35. What horizontal units do you require?

Answer	Responses

Geographic coordinates in degrees, minutes, seconds	20
Geographic coordinates in decimal degrees	27
Meters	87
U.S. Survey Feet	41
International Feet	5

36. What Vertical units do you require?

Answer	Responses
Meters	79
U.S. Survey Feet	68
International Feet	5

37. Do you have cost ceilings per square mile for the elevation data that you require?

Answer	Responses
Yes	25
No	65

38. If "Yes," the maximum NRCS would pay is $__/mi^2.

- Numbers varied from $100 to $5,000/mi^2 [This question obviously confused respondents.]
- Don't know; always ceilings
- Depends on budget

39. Has your organization programmed funding for FY2010/2011 and beyond for High Resolution Elevation Data?

Answer	Responses
Yes	15
No	73

40. If "Yes," what amount per year?

- Several replied $50K for FY 2010
- One replied $500K to $1M
- Most replied "Don't know"

41. Where should your elevation data be housed for dissemination?

Answer	Responses
USGS	11
NRCS	34
USGS & NRCS partnership	72
Locally	32
Other (please specify)	14

No alternatives specified.

42. How should users access and/or pay for the data?

Answer	Responses
FTP with no charge to Federal users	30
FTP with charge to non-Federal users	4
FTP with no charge to any users	34
DVD shipment with no charge to Federal users	10
DVD shipment with charge to non-Federal users	5
DVD shipment with no charge to any users	7
ArcGIS Server and process models via web services	22
Other	7

43. Can you accept elevation data licensed to NRCS that is not in the public domain?

Answer	Responses
Yes	61
No	17
Maybe, under some circumstances, if there are significant cost savings	29

44. Is your organization pursuing partnerships with other federal and/or state organizations for cost sharing of elevation projects?

Answer	Responses
Yes	65
No	32

45. If "yes," please explain your partnership pursuits.

- Numerous replies refer to various federal (USGS, NOAA, USACE, FEMA, NRCS, BLM), state (various departments), county and/or university partnerships.
- Kansas GIS policy board has made elevation its top priority for acquisition. We work as a group to define partnerships and define areas of interest to gain efficiencies in acquisition of LIDAR data each year. We have as a state defined a LIDAR standard that we have used the last two years to acquire LIDAR data. Kansas has one team of stakeholders from all levels of government that meet to make decisions on LIDAR and develop documents to work with legislature to pursue funds. The one thing we are still missing is a good funding source with the declining budgets.
- Puget Sound LiDAR Consortium & Oregon LiDAR Consortium have set a high data standard adopted by WA, OR, ID; through the (Oregon) state agency named "DOGAMI"
- We are active participants with the National Digital Elevation Program (NDEP); we submit elevation projects to NDEP Tracker at http: //ndep.gov
- We have initiated some local partnerships, however will not enter into NDEP due to proprietary nature of the data sought for remainder of the state. I
- In Minnesota, we have a group under the Governor's Council for Elevation; there are interested parties from federal, state and local governments.
- New York State Dept of Environmental Control (NYSDEC)
- In Texas, the cartography group in liaison in talks with state, county and special interest groups promoting new elevation data acquisitions on a collaborative basis
- Seeking ARRA funding
- http://www.wlia.org/wilandinfo/task+forces/orthoimagery.asp
  this link explains the task force. It is primarily for imagery but has an elevation component.

46. Does your organization have existing partnerships with other federal and/or state organizations for cost sharing of elevation projects?

Answer	Responses
Yes	47
No	50

47. If "yes," please explain your existing partnership.

- Many responses were repeated from question 45.
- USGS, Jim Mauck, NDEP

- The FY2009 partnership is between NRCS, USGS, Corp of Engineers, Kansas Department of Agriculture, and Kansas Water Office to acquire approximately 9 counties of 1.4 meter LIDAR data. Since we do not have a dedicated funding source the partnership varies on a yearly basis depending on who comes to the table with a need and funds.
- We are currently partnered with 11 different entities on a project. It is more effective for us to leverage our funds with other groups.
- Have cost-shared with local consortiums that included State & Local Government as well as State and Federal Research Institutions
- There is a partnership for imagery, but not elevation data that I know of.
- USGS, NRCS, USFWS, FGDC
- NRCS partnerships with Conservation Districts
- Arkansas Geostor
- Through the State agency named "DOGAMI" we have an agreement whereby the OR LiDAR Consortium can pay into a pool to obtain LiDAR.

48. The vertical accuracy of elevation data has the most direct correlation to the overall cost of an elevation dataset. As stated above, how would you best describe your justification for vertical accuracy?

Answer	Responses
We absolutely must have elevation data with the vertical accuracy specified	38
Whereas we need elevation data with the vertical accuracy specified, we could accept something less	54
Our specified vertical accuracy could best be summarized as "nice to have" rather than necessary	13
Other (please specify)	10

Other: Additional responses indicated that accuracy requirements would be determined by each project. However, several recommended that elevation data be obtained at the highest requirement level, it can then be generalized for other projects that require less accuracy.

49. For your prior or current LiDAR or IFSAR projects, please summarize the projects, costs, applications and benefits to your organization

Please see Appendix C for detailed responses to this question

50. For your prior or current LiDAR or IFSAR projects, please summarize any lessons-learned, to include applications and best management practices.

Please see Appendix D for detailed responses to this question

51. Does your organization currently contract for LiDAR data acquisition, products and/or services?

Answer	Responses
Yes	36
No	69

52. Does your organization have the personnel resources, hardware and software to work with LiDAR?

Answer	Responses
Yes	97
No	17

53. What are your data management plans for the LiDAR data?

Answer	Responses
Storage using local hard disks	40
External drives	71
Server	57
On-line server	20
Other (please specify)	14

Others: All said "to be determined"

54. Do you currently use intensity imagery from LiDAR for any applications?

Answer	Responses
Yes	13
No	95

55. If "yes," please explain your use and benefits of intensity imagery.

- Need imagery that matches elevation
- Photo backdrop for visual interpretation
- Used for breaklines and hydro-enforcement

- Interpret artifacts, basic classification
- Intensity used as a tool for working with soil surveys
- Merge with or use in association with NAIP, veg indexes
- Unsuccessful for vegetation analysis because images were 8-bit; when images go to 16-bit I would like to re-try
- Colorize to show areas of uncertainty related to bare earth terrain

56. Please check all of the tangible benefits your organization might receive by using LiDAR data. They measure, in dollar savings, the impact of an activity on people, equipment, time, space and facilities, and support materials.

Answer	Responses
None	2
Increased revenue	7
Cost reduction	96
Cost avoidance	62
Other (please specify, see Question 57)	25

57. Briefly explain any tangible benefits of LiDAR data as relevant to your organization.

Please see Appendix E for detailed responses to this question

58. Please check all of the intangible benefits your organization might receive by using LiDAR data. Intangible benefits are subjective issues that can strongly influence the decision to undertake an effort, but can seldom be measured in dollar terms.

Answer	Responses
None	0
Better and/or timelier decision-making	94
More accurate information	104
Better reporting	37
Improved public safety	27
Improved environmental protection	60
Better support of NRCS/Division mission	90
Better support of states	37
Other (please specify, see Question 59)	3

59. Briefly explain any intangible benefits of LiDAR data as pertains to your organization.

Please see Appendix E for detailed responses to this question

60. Does your organization currently contract for IFSAR data acquisition, products and/or services?

Answer	Responses
Yes	16
No	81

61. Does your organization currently use IFSAR ortho-rectified radar imagery (ORI) for any applications?

Answer	Responses
Yes	24
No	73

62. Does your organization have the personnel resources, hardware and software to work with IFSAR?

Answer	Responses
Yes	56
No	40

63. Please check all of the tangible benefits your organization might receive by using IFSAR data. They measure, in dollar savings, the impact of an activity on people, equipment, time, space and facilities, and support materials.

Answer	Responses
None	21
Increased revenue	4
Cost reduction	44
Cost avoidance	28
Other (please specify, see Question 64)	11

64. Briefly explain any tangible benefits of IFSAR data as relevant to your organization.

Please see Appendix E for detailed responses to this question

65. Please check all of the intangible benefits your organization might receive by using IFSAR data. Intangible benefits are subjective issues that can strongly influence the decision to undertake an effort, but can seldom be measured in dollar terms.

Answer	Responses
None	20
Better and/or timelier decision-making	42
More accurate information	46
Better reporting	20
Improved public safety	11
Improved environmental protection	25
Better support of NRCS/Division mission	37
Better support of states	16
Other (please specify, see Question 66)	13

66. Briefly explain any intangible benefits of IFSAR data as pertains to your organization.

Please see Appendix E for detailed responses to this question

67. Do you currently use elevation data from the National Elevation Dataset (NED)?

Answer	Responses
No, never	20
Yes, often	50
Yes, occasionally	47

68. If you never use elevation data from the NED, what are your reasons for not using NED data? (use all that apply)

Answer	Responses
Vertical accuracy is not good enough	34
Post spacing is not dense enough	23
NED data is obsolete where I need it	7
NED data is not available where I neet it	9
DSM is needed, but NED has DTM only	2
Wrong file format	0
Other (please specify)	10

Other:

- NED products are a little inconsistent.
- Arkansas has little high resolution elevation.
- NED data work fine in areas of high relief in most cases for large area general terrain analysis, some areas don't work though.
- Have better data from UCONN CLEAR.
- Used for rough planning but vertical accuracy not adequate for detailed planning/design.

Some respondents were unfamiliar with the NED:

- I was unaware of this resource.
- Don't know if available.
- Not familiar with this product.
- Not used in some areas.

69. Does your data get submitted to the NED for use by others?

Answer	Responses
Yes	30
No	67

70. Do you participate in developing partnerships with National Digital Elevation Program (NDEP) members by using the elevation project tracker at http://www.ndep.gov?

Answer	Responses
Yes	16
No	96

71. Do you have any specific recommendations on how NRCS should address diverse needs for elevation data from different NRCS Divisions and different states?

Please see Appendix F for detailed responses to this question

Appendix C – NRCS DEM Project Applications

NRCS High-Use DEM Applications

Table C.1 summarizes the number of questionnaire responses for the highest use DEM applications within NRCS and the relevance of each application to the six NRCS Divisions[1].

Table C.2 — High-Use DEM Applications by NRCS Division

Keywords	Number	CED	CPD	EPD	ESD	RIAD	SSD
Soils Mapping	73	X	X	X	X	X	X
Engineering	52	X	X		X		
Wetlands	51	X	X	X	X	X	X
Conservation	47	X	X		X		
3-D Modeling and Terrain Analysis	36	X	X	X	X	X	X
Engineering Design	23	X					
Easements	21		X	X	X		
Planning	20	X	X	X	X	X	X

Soils Mapping

In response to Question 8, a total of 73 respondents indicated that DEMs were used by NRCS for soils mapping. Subsequently, in response to Question 49, many respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for soils mapping:

- LIDAR data is being used to update soils in order to make them better and more accurate. This somewhat of an abstraction which is difficult to quantify monetarily.
- NGDC funded a LiDAR project for Pine County, MN. This project cost approximately $6/ac ($163,600). We are using the data for modeling soil survey. Other agencies and other users w/in NRCS are also using the data. It had been made publically available via the Minnesota DNR Website and they also provided funding to upgrade the data to FEMA specifications. We also have 21 tiles of IFSAR data in Lake and Cook County that we have been using for premapping and will be using for modeling once there is more field investigation complete.

[1] The six NRCS Divisions include: Conservation Engineering Division (CED), Conservation Planning Division (CPD), Easement Programs Division (EPD), Ecological Site Division (ESD), Resources Inventory and Assessment Division (RIAD), and Soil Survey Division (SSD)

- The use of LiDAR for the initial mapping in Winston County, Alabama has allowed for more precise soil line placement, saved time in the field by delineating breaks in the landform and provided for the spatial analysis of landforms/GPS points. There has been considerable cost savings by allowing the soil scientist to detect changes in the landscape and navigate to that particular site efficiently. The LiDAR derivatives such as hillshade, slopes, contours have enabled the Soil Scientist to create a highly accurate pre-map prior to going to the field.

- How do you put a cost on improving the quality of your soil survey data and generating higher quality soil survey interpretations?

- We are currently using LiDAR in Dodge County, WI to adjust mapunit boundaries to landform. Other benefits of using LiDAR within Soil Survey include evaluating the composition of mapunits with respect to slope, aspect, planform or curvature.

- Limited use for soil survey premapping, slope classes, digital soil mapping (raster based), flood plain determination, landform ID. Increases accuracy, precision, and efficiency. Reported good return on investment.

- We have an initial soil survey underway using 1m resolution LiDAR. The cost to acquire the LIDAR in 2005 was $100,000 for 450,000 acres. The DEM is used in all phases of mapping now, which is a completely digital process, punctuated by field checking. The 1m resolution is essential for us to be able to visualize the terrain and accurately delineate landforms and areas that are dominated by different parent materials. We then process the 1m data to a 5m pixel size for further work (soil inference). We have mapped over 230,000 acres at an order two level of detail since 2007, and without the 1m LiDAR, this would not have been possible.

- Soil Survey of Isle Royale National Park, cost of LIDAR was $55,000 for a survey area of 179,000 acres. One unique application was a mapunit slope analysis. Benefits was greatly increased accuracy of mapunit delineations and less field time required to make better soil maps.

- County government shared LiDAR with NRCS Soil Survey for the update soil mapping. FEMA shared LiDAR with Engineering for Dam Rehabilitation and Inundation projects. Both projects saved $ by cutting data collection time in the field by NRCS employees.

- Projects with other federal and state partners have been a great success for all stakeholders. We are just beginning to work with the data, but there will certainly be benefits to the agency in terms of improvements to soil survey accuracy, hydrologic analysis, HEL determination, irrigation planning, and many other applications.

- Oregon NRCS has participated in a few partnership data collections, in ag, range and forest areas. Costs are generally around $549/sq.mi. Uses include soil mapping and ag engineering. Benefits include more accurate delineation of soil map units, and increased efficiency in laying out engineering practices.

- Lincoln County LiDAR project. Total cost ~ $340,000 to cover the soil survey area. Benefits include accurate characterization/classification of landform and detection of surface features on Order 2 (very detailed) agricultural lands indicative of soil surface properties, drainage class, and with help of our CIR imagery, presence of shallow, wet, and/or saline areas. 1st return minus bare earth, along with our 1m CIR imagery is expected to help us predict general vegetative communities on rangeland and forested areas. Again, in conjunction with our CIR, we expect to be able to detect presence/absence of significant rock fragment at the surface- an attribute that can prove highly limiting for land utilization.

- 2004-Story, WY used for WUI (wildland urban fire interface) biomass analysis and dam breach analysis. Clear Creek/ Buffalo used for soil survey, floodplain mapping. Dull Knife Res/N Fork Powder River dam breach analysis. Kaycee, WY/M Fork Powder River, floodwall design and flood remediation. Casper Mountain, WUI vegetation management, biomass/fuels analysis, fire hazard analysis. The 2004 project cost approx $100k for these 5 project areas but that includes high-res 4-band imagery and breaklines. 2006-Lander/M Fork Popo Agie River, floodwall design, flood planning, $80K.

- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design Projects: Coverage currently for 13 counties/115; Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning

- NRCS didn't pay a cent for the LIDAR data we are using and it has significantly improved the accuracy of soil survey delineations.

- Walsh County/Forest River Watershed LIDAR $200,000 - WAFFLE Water Storage Project, Soil Survey

- Central North Dakota IFSAR Project
  $25,000 - ARS Wetland Review & NRCS Wetland Modeling Project, Soil Survey Activities.

- Upper James/Pipestem Watershed
  $50,000 - Soil Survey Updates, Enhanced Resource Maps, Wetland Review

- Red River Basin Mapping Initiative LIDAR
  $300,000 - Floodplain Mapping, Regional Scale Watershed Management, Soil Survey, Wetland Review. IFSAR 2008 $300,000 - Soil Survey, Wetland Review
  IFSAR 2009

- Two IFSAR products were ordered for the soil survey program in Arizona in 2007. The two areas encompassed approximately 6,000 square miles total. The DTMs and DSMs were used for landform analysis for initial soil survey application. The high resolution (5 meter) data was beneficial for advanced pre-mapping techniques in remote areas and for creating detailed elevation derivatives.

Engineering

In response to Question 8, a total of 52 respondents indicated that DEMs were used by NRCS for engineering applications. Subsequently, in response to Question 49, respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for engineering:

- Engineers are using LIDAR data as a substitute for the need to do topographic surveys. On a typical project this can reduce 2-3 days field work to 1/2-3/4's of a day using LIDAR. That is extremely significant given how much surveying NRCS staff do.

- Significant reduction in engineering and hydrologic field surveys. Significant reduction in staff hours of field work and office data processing.

- County wide LiDAR acquired in 2005 at a cost of $400,000. Used for flood mapping, conservation engineering practices, conservation farm planning, hydrologic analysis in ArcGIS, 3D modeling for presentations, and other uses are being identified. It is possibly one of the best assets the department has invested in.

- County government shared LiDAR with NRCS Soil Survey for the update soil mapping. FEMA shared LiDAR with Engineering for Dam Rehabilitation and Inundation projects. Both projects saved $ by cutting data collection time in the field by NRCS employees.

- We have begun using LiDAR for some of our preliminary engineering and planning needs (e.g. prelim Hydrological assessment, Emergency Watershed Protection response). We recently leveraged $100K NRCS dollars with Oregon LiDAR Consortium dollars and got more than a million dollars worth of data.

- Recent purchase of LiDAR with a number of partners leveraged $1.2 million worth of LiDAR for only a $70K investment from NRCS. LiDAR used for irrigation related planning and engineering as well as vegetation and riparian shading analysis.

- We have used LIDAR to obtain reasonably good elevation data (1 foot accuracy) over areas of 10,000-60,000 acres. Applications were for planning of large scale engineering projects including river modeling. The benefits were obvious as these projects couldn't have been reasonably accomplished without use of this technology. Both these projects date back from 2003-2005 and I cannot recall specific costs although I know it was expensive.

- Oregon NRCS has participated in a few partnership data collections, in ag, range and forest areas. Costs are generally around $549/sq.mi. Uses include soil mapping and ag engineering.

Benefits include more accurate delineation of soil map units, and increased efficiency in laying out engineering practices.

- LIDAR was acquired with EWP funds for flooding in SW Utah. The total cost was about $100,000. The data was used by engineering staff and contractors to design and construct rip-rap protection of rivers.
- Flood routing, engineering design, survey time drastically reduced, watershed modeling for hydraulics.

Wetlands

In response to Question 8, a total of 51 respondents indicated that DEMs were used by NRCS for wetlands applications. Subsequently, in response to Question 49, a few respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for wetland determination, modeling or review:

- We have purchased IFSAR for a number of areas in South Dakota. Costs of each purchase range from $50-100K. We use IFSAR to do update SSURGO mapping and to assist in wetland determination and extent.

- Central North Dakota IFSAR Project
  $25,000 - ARS Wetland Review & NRCS Wetland Modeling Project, Soil Survey Activities.

- Upper James/Pipestem Watershed
  $50,000 - Soil Survey Updates, Enhanced Resource Maps, Wetland Review

- Red River Basin Mapping Initiative LIDAR
  $300,000 - Floodplain Mapping, Regional Scale Watershed Management, Soil Survey, Wetland Review. IFSAR 2008 $300,000 - Soil Survey, Wetland Review
  IFSAR 2009

Conservation

In response to Question 8, a total of 47 respondents indicated that DEMs were used by NRCS for conservation applications. Subsequently, in response to Question 49, two respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for such applications:

- County wide LiDAR acquired in 2005 at a cost of $400,000. Used for flood mapping, conservation engineering practices, conservation farm planning, hydrologic analysis in ArcGIS, 3D modeling for presentations, and other uses are being identified. It is possibly one of the best assets the department has invested in.

- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design Projects: Coverage currently for 13 counties/115; Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning.

3D Modeling and Terrain Analysis

In response to Question 8, a total of 36 respondents indicated that DEMs were used by NRCS for terrain analysis applications, including 3D modeling; analyses of topography, contours, landforms, and elevation derivatives including breaklines, slope, aspect and curvature. Subsequently, in response to Question 49, respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for such applications:

- We are applying LIDAR elevation data and derivatives to every aspect of work for NRCS in NC producing high quality products at a lower cost.

- Two IFSAR products were ordered for the soil survey program in Arizona in 2007. The two areas encompassed approximately 6,000 square miles total. The DTMs and DSMs were used for landform analysis for initial soil survey application. The high resolution (5 meter) data was beneficial for advanced pre-mapping techniques in remote areas and for creating detailed elevation derivatives.

- We are currently using LiDAR in Dodge County, WI to adjust mapunit boundaries to landform. Other benefits of using LiDAR within Soil Survey include evaluating the composition of mapunits with respect to slope, aspect, planform or curvature. Better accuracy than guessing off of a USGS Quad sheet.

- Benefits have been increased accuracy of preliminary plans for structures so that cost estimates are closer, as well as saved staff time for in-field surveying. We are still evaluating the degree to which the data can save design time on structures. Still institutionalizing the data - many standard processes rely on contours or field survey.

- The use of LiDAR for the initial mapping in Winston County, Alabama has allowed for more precise soil line placement, saved time in the field by delineating breaks in the landform and provided for the spatial analysis of landforms/GPS points. There has been considerable cost savings by allowing the soil scientist to detect changes in the landscape and navigate to that particular site efficiently. The LiDAR derivatives such as hillshade, slopes, contours have enabled the Soil Scientist to create a highly accurate pre-map prior to going to the field.

- Limited use for soil survey premapping, slope classes, digital soil mapping (raster based), flood plain determination, landform ID. Increases accuracy, precision, and efficiency. Reported good return on investment.

- We have an initial soil survey underway using 1m resolution LiDAR. The cost to acquire the LIDAR in 2005 was $100,000 for 450,000 acres. The DEM is used in all phases of mapping now, which is a completely digital process, punctuated by field checking. The 1m resolution is essential for us to be able to visualize the terrain and accurately delineate landforms and areas that are dominated by different parent materials. We then process the 1m data to a 5m pixel size for further work (soil inference). We have mapped over 230,000 acres at an order two level of detail since 2007, and without the 1m LiDAR, this would not have been possible.

- Soil Survey of Isle Royale National Park, cost of LIDAR was $55,000 for a survey area of 179,000 acres. One unique application was a mapunit slope analysis. Benefits was greatly increased accuracy of mapunit delineations and less field time required to make better soil maps.

- County wide LiDAR acquired in 2005 at a cost of $400,000. Used for flood mapping, conservation engineering practices, conservation farm planning, hydrologic analysis in ArcGIS, 3D modeling for presentations, and other uses are being identified. It is possibly one of the best assets the department has invested in.

- We get 20 to 30 eqip sign-ups per year with various practices that are on relatively flat terrain so a typical topographic map will not show very many contours in the area we are looking at proposing practices. Underground outlets, sub surface drains, and pipelines it is nice if we have a good indication of which way the ground is sloping. I have found that LiDAR has been fairly accurate for most projects we work on since it is mostly open ground. Saves us a drive out to field at planning stage, then we can verify for design is participant is selected for cost share.

- Recent purchase of LiDAR with a number of partners leveraged $1.2 million worth of LiDAR for only a $70K investment from NRCS. LiDAR used for irrigation related planning and engineering as well as vegetation and riparian shading analysis.

- Lincoln County LiDAR project. Total cost ~ $340,000 to cover the soil survey area. Benefits include accurate characterization/classification of landform and detection of surface features on Order 2 (very detailed) agricultural lands indicative of soil surface properties, drainage class, and with help of our CIR imagery, presence of shallow, wet, and/or saline areas. 1st return minus bare earth, along with our 1m CIR imagery is expected to help us predict general vegetative communities on rangeland and forested areas. Again, in conjunction with our CIR, we expect to be able to detect presence/absence of significant rock fragment at the surface- an attribute that can prove highly limiting for land utilization.

- 2004-Story, WY used for WUI (wildland urban fire interface) biomass analysis and dam breach analysis. Clear Creek/ Buffalo used for soil survey, floodplain mapping. Dull Knife Res/N Fork Powder River dam breach analysis. Kaycee, WY/M Fork Powder River, floodwall design and flood remediation. Casper Mountain, WUI vegetation management, biomass/fuels analysis, fire hazard analysis. The 2004 project cost approx $100k for these 5 project areas but that includes high-res 4-band imagery and breaklines. 2006-Lander/M Fork Popo Agie River, floodwall design, flood planning, $80K.

- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design Projects: Coverage currently for 13 counties/115; Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning.

- Two IFSAR products were ordered for the soil survey program in Arizona in 2007. The two areas encompassed approximately 6,000 square miles total. The DTMs and DSMs were used for landform analysis for initial soil survey application. The high resolution (5 meter) data was beneficial for advanced pre-mapping techniques in remote areas and for creating detailed elevation derivatives.

Engineering Design

In response to Question 8, a total of 23 respondents indicated that DEMs were used by NRCS for engineering design applications. Subsequently, in response to Question 49, two respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for such applications:

- Benefits have been increased accuracy of preliminary plans for structures so that cost estimates are closer, as well as saved staff time for in-field surveying. We are still evaluating the degree to which the data can save design time on structures. Still institutionalizing the data - many standard processes rely on contours or field survey.

- Flood routing, engineering design, survey time drastically reduced, watershed modeling for hydraulics.

- We get 20 to 30 eqip sign-ups per year with various practices that are on relatively flat terrain so a typical topographic map will not show very many contours in the area we are looking at proposing practices. Underground outlets, sub surface drains, and pipelines it is nice if we have a good indication of which way the ground is sloping. I have found that LiDAR has been fairly accurate for most projects we work on since it is mostly open ground. Saves us a drive out to field at planning stage, then we can verify for design is participant is selected for cost share.

- CADD users are able to evaluate preliminary designs prior to fieldwork. Field surveys can be narrowed to specific areas, reducing the amount of time spent.

- Kaycee, WY/M Fork Powder River, floodwall design and flood remediation. 2006-Lander/M Fork Popo Agie River, floodwall design, flood planning, $80K.

- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design. Coverage currently for 13 counties. Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning.

- LIDAR was acquired with EWP funds for flooding in SW Utah. The total cost was about $100,000. The data was used by engineering staff and contractors to design and construct rip-rap protection of rivers.

Easements

In response to Question 8, a total of 21 respondents indicated that DEMs were used by NRCS for easement applications. However, in response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for such applications. The use of DEMs for easements is assumed to be linked to other applications such as conservation, wetlands, floodplains, forests, etc.

Planning

In response to Question 8, a total of 20 respondents indicated that DEMs were used by NRCS for planning activities. Subsequently, in response to Question 49, respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for such various planning applications:

- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design. Coverage currently for 13 counties. Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning.

- We have used LIDAR to obtain reasonably good elevation data (1 foot accuracy) over areas of 10,000-60,000 acres. Applications were for planning of large scale engineering projects including river modeling. The benefits were obvious as these projects couldn't have been reasonably accomplished without use of this technology. Both these projects date back from 2003-2005 and I cannot recall specific costs although I know it was expensive.

- Benefits have been increased accuracy of preliminary plans for structures so that cost estimates are closer, as well as saved staff time for in-field surveying. We are still evaluating the degree to which the data can save design time on structures.

- I have found that LiDAR has been fairly accurate for most projects we work on since it is mostly open ground. Saves us a drive out to field at planning stage, then we can verify for design is participant is selected for cost share.

- [With DEMs], able to provide more complete and better information for planning than was previously available.

- County wide LiDAR acquired in 2005 at a cost of $400,000. Used for flood mapping, conservation engineering practices, conservation farm planning, hydrologic analysis in ArcGIS, 3D modeling for presentations, and other uses are being identified. It is possibly one of the best assets the department has invested in.

- Projects with other federal and state partners have been a great success for all stakeholders. We are just beginning to work with the data, but there will certainly be benefits to the agency in terms of improvements to soil survey accuracy, hydrologic analysis, HEL determination, irrigation planning, and many other applications.

- We have begun using LiDAR for some of our preliminary engineering and planning needs (e.g. prelim Hydrological assessment, Emergency Watershed Protection response). We recently leveraged $100K NRCS dollars with Oregon LiDAR Consortium dollars and got more than a million dollars worth of data.

- Recent purchase of LiDAR with a number of partners leveraged $1.2 million worth of LiDAR for only a $70K investment from NRCS. LiDAR used for irrigation related planning and engineering as well as vegetation and riparian shading analysis.

- The RC&D Council has numerous projects that could use LIDAR and some that are dead without it. We have weed projects that are analyzed year after year to see weed progression or retreat, flooding problems in a few different towns, large park design projects, and forestry issues that are bad. We need to be able to evaluate Pine Beetle damage that is taking out up to 90% of evergreen trees in our forests. LIDAR could assist tremendously in planning efforts year after year.

- 2004-Story, WY used for WUI (wildland urban fire interface) biomass analysis and dam breach analysis. Clear Creek/ Buffalo used for soil survey, floodplain mapping. Dull Knife Res/N Fork Powder River dam breach analysis. Kaycee, WY/M Fork Powder River, floodwall design and flood remediation. Casper Mountain, WUI vegetation management, biomass/fuels analysis, fire hazard analysis. The 2004 project cost approx $100k for these 5 project areas but that includes high-res 4-band imagery and breaklines. 2006-Lander/M Fork Popo Agie River, floodwall design, flood planning, $80K.

NRCS Mid-Use DEM Applications

Table C.2 summarizes the number of questionnaire responses for the mid-use DEM applications within NRCS and the relevance of each application to the six NRCS Divisions.

Table C.2 —Mid-Use DEM Applications by NRCS Division

Keywords	Number	CED	CPD	EPD	ESD	RIAD	SSD
Dams	18	X	X		X		X
Hydrology & Hydraulics	18	X	X	X	X	X	
Floodplain Mapping/Analysis	14	X	X	X	X	X	X
Forest and/or Vegetation Analysis	14		X	X	X	X	X
Irrigation Systems	11	X	X		X	X	X
Precision Agriculture	9		X				X
Watershed Management	9	X	X	X	X	X	X
Erosion Control	8	X	X	X		X	X
Pipelines	8	X	X				X
Ponds	7	X	X	X	X	X	X

Dams

In response to Question 8, a total of 18 respondents indicated that DEMs were used by NRCS for dam activities. Subsequently, in response to Question 49, a few respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for dam applications:

- County government shared LiDAR with NRCS Soil Survey for the update soil mapping. FEMA shared LiDAR with Engineering for Dam Rehabilitation and Inundation projects. Both projects saved $ by cutting data collection time in the field by NRCS employees.
- 2004-Story, WY used for WUI (wildland urban fire interface) biomass analysis and dam breach analysis. Clear Creek/ Buffalo used for soil survey, floodplain mapping. Dull Knife Res/N Fork Powder River dam breach analysis.
- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design. Coverage currently for 13 counties. Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning.

Hydrology & Hydraulics

In response to Question 8, a total of 18 respondents indicated that DEMs were used by NRCS for hydrologic and/or hydraulic applications. Subsequently, in response to Question 49, respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for such H&H applications:

- Projects with other federal and state partners have been a great success for all stakeholders. We are just beginning to work with the data, but there will certainly be benefits to the agency in terms of improvements to soil survey accuracy, hydrologic analysis, HEL determination, irrigation planning, and many other applications.
- County wide LiDAR acquired in 2005 at a cost of $400,000. Used for flood mapping, conservation engineering practices, conservation farm planning, hydrologic analysis in ArcGIS, 3D modeling for presentations, and other uses are being identified. It is possibly one of the best assets the department has invested in.
- Significant reduction in engineering and hydrologic field surveys. Significant reduction in staff hours of field work and office data processing.
- Flood routing, engineering design, survey time drastically reduced, watershed modeling for hydraulics.
- We have begun using LiDAR for some of our preliminary engineering and planning needs (e.g. prelim Hydrological assessment, Emergency Watershed Protection response). We recently leveraged $100K NRCS dollars with Oregon LiDAR Consortium dollars and got more than a million dollars worth of data.

Floodplain Mapping/Analysis

In response to Question 8, a total of 14 respondents indicated that DEMs were used by NRCS for floodplain mapping or analysis. Subsequently, in response to Question 49, respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application:

- County wide LiDAR acquired in 2005 at a cost of $400,000. Used for flood mapping, conservation engineering practices, conservation farm planning, hydrologic analysis in ArcGIS, 3D modeling for presentations, and other uses are being identified. It is possibly one of the best assets the department has invested in.
- Wray CO, determine potential flooding hazards associated with aging flood detention structures. Patterson Hollow, CO - Identify areas in existing canals that may overflow during heavy storm events.

- The RC&D Council has numerous projects that could use LIDAR and some that are dead without it. We have weed projects that are analyzed year after year to see weed progression or retreat, flooding problems in a few different towns, large park design projects, and forestry issues that are bad. We need to be able to evaluate Pine Beetle damage that is taking out up to 90% of evergreen trees in our forests. LIDAR could assist tremendously in planning efforts year after year. [Note: Vegetation impacts both H&H modeling and floodplain analysis.]

- 2004-Clear Creek/ Buffalo used for soil survey, floodplain mapping. Dull Knife Res/N Fork Powder River dam breach analysis. Kaycee, WY/M Fork Powder River, floodwall design and flood remediation. 2006-Lander/M Fork Popo Agie River, floodwall design, flood planning, $80K.

- LIDAR was acquired with EWP funds for flooding in SW Utah. The total cost was about $100,000. The data was used by engineering staff and contractors to design and construct rip-rap protection of rivers.

- Red River Basin Mapping Initiative LIDAR. $300,000 - Floodplain Mapping, Regional Scale Watershed Management, Soil Survey, Wetland Review.

- The LiDAR acquisition was for an EWP flooding event at a cost of about $100,000. The benefit was that a survey did not need to be taken near flood zones and was much faster.

- Limited use for soil survey premapping, slope classes, digital soil mapping (raster based), flood plain determination, landform ID. Increases accuracy, precision, and efficiency. Reported good return on investment.

- County wide LiDAR acquired in 2005 at a cost of $400,000. Used for flood mapping, conservation engineering practices, conservation farm planning, hydrologic analysis in ArcGIS, 3D modeling for presentations, and other uses are being identified. It is possibly one of the best assets the department has invested in.

- Flood routing, engineering design, survey time drastically reduced, watershed modeling for hydraulics.

Forest/Vegetation Analysis

In response to Question 8, a total of 14 respondents indicated that DEMs were used by NRCS for analysis of forests and/or vegetation. Subsequently, in response to Question 49, respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application:

- 2004-Story, WY used for WUI (wildland urban fire interface), biomass analysis and dam breach analysis. Casper Mountain, WUI vegetation management, biomass/fuels analysis, fire hazard analysis. The 2004 project cost approx $100k for these 5 project areas but that includes high-res 4-band imagery and breaklines.

- The RC&D Council has numerous projects that could use LIDAR and some that are dead without it. We have weed projects that are analyzed year after year to see weed progression or retreat, flooding problems in a few different towns, large park design projects, and forestry issues that are bad. We need to be able to evaluate Pine Beetle damage that is taking out up to 90% of evergreen trees in our forests. LIDAR could assist tremendously in planning efforts year after year.

- Oregon NRCS has participated in a few partnership data collections, in ag, range and forest areas. Costs are generally around $549/sq.mi. Uses include soil mapping and ag engineering. Benefits include more accurate delineation of soil map units, and increased efficiency in laying out engineering practices.

- Lincoln County LiDAR project. Total cost ~ $340,000 to cover the soil survey area. Benefits include accurate characterization/classification of landform and detection of surface features on Order 2 (very detailed) agricultural lands indicative of soil surface properties, drainage class, and with help of our CIR imagery, presence of shallow, wet, and/or saline areas. 1st return minus bare earth, along with our 1m CIR imagery is expected to help us predict general vegetative communities on rangeland and forested areas. Again, in conjunction with our CIR, we expect to be able to detect presence/absence of significant rock fragment at the surface- an attribute that can prove highly limiting for land utilization.

Irrigation Systems

In response to Question 8, a total of 11 respondents indicated that DEMs were used by NRCS for irrigation applications. Subsequently, in response to Question 49, two respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application:

- Recent purchase of LiDAR with a number of partners leveraged $1.2 million worth of LiDAR for only a $70K investment from NRCS. LiDAR used for irrigation related planning and engineering as well as vegetation and riparian shading analysis.

- Projects with other federal and state partners have been a great success for all stakeholders. We are just beginning to work with the data, but there will certainly be benefits to the agency in terms of improvements to soil survey accuracy, hydrologic analysis, HEL determination, irrigation planning, and many other applications.

Precision Agriculture

In response to Question 8, a total of 9 respondents indicated that DEMs were used by NRCS for prevision agriculture. However, in response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application by NRCS. Furthermore, questions 19 through 27 pertain to Precision Agriculture; but NRCS personnel, surprisingly, do not appear to be actively involved with this technology.

The term "surprisingly" is used because the authors of the *National Height Modernization Study: Report to Congress* (published by NOAA) interviewed members of the Precision Agriculture community in preparation of this report for NOAA in 1998 and concluded cost benefits of billions of dollars by using GPS receivers on farm equipment and tailoring the application of water, fertilizer, etc. on a per-square-meter basis. The promotion of agricultural productivity would appear to be of vital interest to NRCS.

Several participants at an NRCS DEM workshop indicated that NRCS had established a policy, years ago, to avoid promotion of Precision Agriculture technology which was to be left in the hands of the private sector.

Watershed Management

In response to Question 8, a total of 9 respondents indicated that DEMs were used by NRCS for watershed management. Subsequently, in response to Question 49, respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application:

- Red River Basin Mapping Initiative LIDAR. $300,000 - floodplain mapping, regional scale watershed management, soil survey, wetland review. IFSAR 2008 $300,000 - soil survey, wetland review.
- Flood routing, engineering design, survey time drastically reduced, watershed modeling for hydraulics.
- We have begun using LiDAR for some of our preliminary engineering and planning needs (e.g. preliminary hydrological assessment, emergency watershed protection response). We recently leveraged $100K NRCS dollars with Oregon LiDAR Consortium dollars and got more than a million dollars worth of data.
- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design. Coverage currently for 13 counties. Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning.
- Walsh County/Forest River watershed LIDAR $200,000 - WAFFLE water storage project, soil survey
- Upper James/Pipestem watershed. $50,000 - Soil Survey Updates, Enhanced Resource Maps, Wetland Review

Erosion Control

In response to Question 8, a total of 8 respondents indicated that DEMs were used by NRCS for erosion control. However, in response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application. Nevertheless, it is widely recognized that LiDAR data is used nationwide by FEMA, NOAA, USACE and states for erosion control purposes. For one project alone, the state of Alaska has spent approximately $20M to mitigate the effects of coastal erosion near a critical facility. Accurate elevation and slope data are vital for control of erosion and farm run-off into our nation's streams.

Pipeline Design

In response to Question 8, a total of 8 respondents indicated that DEMs were used by NRCS for pipeline design. Subsequently, in response to Question 49, one respondent provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application:

- We get 20 to 30 eqip sign-ups per year with various practices that are on relatively flat terrain so a typical topographic map will not show very many contours in the area we are looking at proposing practices. For underground outlets, sub surface drains, and pipelines, it is nice if we have a good indication of which way the ground is sloping. I have found that LiDAR has been fairly accurate for most projects we work on since it is mostly open ground. Saves us a drive out to field at planning stage, then we can verify for design is participant is selected for cost share.

Ponds

In response to Question 8, a total of 7 respondents indicated that DEMs were used by NRCS for pond design. However, in response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application. Nevertheless, it is well known to NRCS personnel that software exists for simple and efficient design of ponds, based on simple queries, provided there is a high resolution DEM available for the general areas in which ponds are desired. This software has been demonstrated at two of the NRCS DEM workshops during the past year.

NRCS Low-Use DEM Applications

Table C.3 summarizes the number of questionnaire responses for the lower-use DEM applications within NRCS and the relevance of each application to the six NRCS Divisions.

Table C.2 —Low-Use DEM Applications by NRCS Division

Keywords	Number	CED	CPD	EPD	ESD	RIAD	SSD
Cultural Resources	6	X	X	X	X	X	X
Resources Inventory	6		X		X	X	X
Stream Restoration	5	X	X	X	X		
Water Resources	4	X	X		X	X	X
Ecology	3		X	X	X		X

11 Miscellaneous Applications	1	X	X	X	X	X	X

Cultural Resources

In response to Question 8, a total of 6 respondents indicated that DEMs were used by NRCS for cultural resources. However, in response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application.

Resources Inventory

In response to Question 8, a total of 6 respondents indicated that DEMs were used by NRCS for resources inventory. However, in response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application.

Stream Restoration

In response to Question 8, a total of 5 respondents indicated that DEMs were used by NRCS for stream restoration. In response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used specifically for stream restoration, but one referred to the use of DEMs for the Wetland Reserve Program (WRP) restoration planning and for Emergency Watershed Protection (EWP) restoration:

- Missouri: LiDAR Cost - $300/sq mi; Applications - WRP restoration planning, dam breach analysis, watershed planning, soil survey update, conservation practice planning and application, EWP restoration planning and design. Coverage currently for 13 counties. Benefits: 50-90% time savings, depending on the application; much of work can be done at desk, reducing driving and field work; work can start immediately regardless of weather conditions; more alternatives can be considered for planning.

Water Resources

In response to Question 8, a total of 4 respondents indicated that DEMs were used by NRCS for water resources. In response to Question 49, one respondent provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application.

- Walsh County/Forest River Watershed LIDAR $200,000 - WAFFLE Water Storage Project, Soil Survey

Ecology

In response to Question 8, a total of 3 respondents indicated that DEMs were used by NRCS for ecology. However, in response to Question 49, no respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for this application.

Miscellaneous Applications

In response to Question 8, 1 respondent indicated that DEMs were used by NRCS for each of the following applications: riparian condition assessment, land cover assessment, wildfire modeling, stream power index, wetness index, site preparation, mine reclamation, livestock management, landscape modeling, range management, and wildlife habitat management. In response to Question 49, two respondents provided additional details regarding the costs and/or benefits of LiDAR and/or IFSAR DEMs used for these applications.

- Recent purchase of LiDAR with a number of partners leveraged $1.2 million worth of LiDAR for only a $70K investment from NRCS. LiDAR used for irrigation related planning and engineering as well as vegetation and riparian shading analysis.
- 2004-Story, WY used for WUI (wildland urban fire interface) biomass analysis and dam breach analysis. Clear Creek/ Buffalo used for soil survey, floodplain mapping. Dull Knife Res/N Fork Powder River dam breach analysis. Kaycee, WY/M Fork Powder River, floodwall design and flood remediation. Casper Mountain, WUI vegetation management, biomass/fuels analysis, fire hazard analysis. The 2004 project cost approx $100k for these 5 project areas but that includes high-res 4-band imagery and breaklines. 2006-Lander/M Fork Popo Agie River, floodwall design, flood planning, $80K.

Appendix D – NRCS DEM Project Lessons Learned

The following are responses to question 50 that asked for lessons learned from prior or current LiDAR or IFSAR projects, to include QA/QC and best management practices.

LiDAR Specific

1. Main lesson learned was that LIDAR is essential to a cost effective update of soil surveys spatial data, new aerial photography is a waste of money if not used in conjunction with an accurate vertical dataset. I threw away my stereoscope so there is no going back!

2. LiDAR should meet FEMA specifications so that other disciplines can use it as well.

3. There is a fair amount of up-front processing that must be done to make the LiDAR usable, though the level of processing required probably depends on the vendor. There are no standards for processing the data for NRCS/Soil Survey use. It is always possible (and easy) to go to a lower resolution through filtering and resampling; however it is impossible to gain detail in a DEM. Thus, it is critical to start at the highest resolution possible, where accurate visualization of the landscape is possible, rather than have a low-resolution DEM with an end-product that is not accurate.

4. I have done some 10 to 20 acre topo surveys with either a total station or survey grade GPS then compared with available LiDAR data and have found that contours fall within 1/2 ft of each other until I get near tree lines or shelter belts along streams.

5. A comparison of the final difference grid outputs to high resolution aerial photography showed that areas having 0.5 to 1 meter and 1 meter and taller vertical structure were generally accurately located and appeared reasonable. The review also clearly showed the limitations of making TIN coverage from the LiDAR data and then converting TIN to GRID coverages. In various places in the height difference grids there are grid cells showing a height difference where the grid cell is clearly over the river surface. Additionally, the presence of vertical banks on the outside of meander bends may potentially over-represent the percentage of vertical structure within some stream reaches.

6. LIDAR data can be difficult to work with because the files are large and it requires a lot of storage space and processing power. Using the expertise of the tech centers may be important for helping to process the data, resample it to various scales and prepare products that are useful for NRCS personnel at the field office and soil survey office levels. Documentation and recommendations on standard software packages used for processing the data would be helpful as well.

7. In spite of 10 foot postings the beam width was too coarse to realistically use last return as ground truth. [Note: Assumed this comment refers to LiDAR; 10 foot postings are uncommon for LiDAR, but common for IFSAR.]

8. The ESRI type grids have been the easiest to work with since that is the primary software utilized. In our instance the artifacts in the LiDAR were not entirely removed. This required smoothing of the data prior to processing.

9. Inspect every deliverable. Vendors make assumptions with noise in products (i.e. the main use for bare-earth gridded LIDAR is for floodplain mapping and generating 2-foot contours).

10. LIDAR DEM data previously received from vendors has high time requirement to process it into a format useful for engineering applications. Would like to have what we need from the get go.

11. Data management and serving is very difficult and time-consuming; hydro-enforcement is worth the money; simultaneous aerial photography is useful to reference ground conditions to LiDAR

12. LIDAR data most valuable for all past engineering, conservation planning and hydrology projects. IFSAR has been used for Soil Survey projects.

IFSAR Specific

1. In purchasing IFSAR products you need to assure the provider has done all possible to remove artifacts from DTM products, e.g. windbreaks removed. Also, hold the provider to deadlines.

2. We have received IFSAR for multiple counties and have learned that it does a poor job of penetrating vegetative canopy, leaving the "bare earth" model looking artificially "lumpy". In the arid west, these well-vegetated lands are our most valuable. The data need to be especially accurate here, not the opposite.

3. IFSAR data is unable to accurately characterize the bare earth terrain in certain landform features. There is higher uncertainty of slope gradient across the bare earth terrain model.

Standards

1. Considerable staff time is spent in processing data sources in the absence of a standard for the resulting product. Products may not be compatible when combined to provide wide area coverage of land forms and results in inconsistent decision making for soil survey products.

2. Enormous file sizes. Data must have metadata.

QA/QC

1. Have the state GIS specialist involved the project from start to finish; hire a professional contractor to QA/QC the elevation data.

2. Biggest lesson is to set money aside for 3rd party QA/QC through Dewberry.

3. Be able to check accuracy yourself to ensure you are getting what you need in both accuracy and quality data.

4. QA requirements need to be spelled out very clearly. Leaf off conditions are important to us and that was not as clearly indicated in the contract.

5. Biggest lesson is that we need to really look the data over for errors before paying the contractor.

6. Obtained LiDAR data from National Park within another soil survey area and were unsure of data quality as it had no metadata. Apparently it had been sent back for re-processing once, so we are suspicious of quality. Standardized processing and accuracy assessment is critical. Vendors can get away with junk if the local staff doesn't know all the ins and outs of quality assessment. One staff of elevation experts should handle this for NRCS.

7. QC your data when you receive it, even if QC'd independently.

8. Visual assessments, not just quantitative ones, are valuable for conservation planning.

Training and/or Experience

1. Need training in use and management of LiDAR.

2. There has been no established place in NRCS to receive training or standardized methodologies on how to best utilize the data provided. We had to work through this on our own. Seemed to turn out reasonably well, but agency wide this must be a large waste of duplication of efforts time and results that will vary widely from state to state. We tried several sources in the agency that seemed like they could help, but none did.

3. Need field users that have skill set to utilize the LiDAR data for analysis.

4. I need detailed training to improve my digital work processes.

Hardware and/or Software

1. The most important lesson learned is to have a computer with lots of RAM and storage. Also to have software that will not crash when LIDAR is used.

2. Data management and distribution will need a system that our computer network can manage.

3. Large file sizes of data set are an issue that needs to be handled.

4. Data storage is not a huge issue, since portable hard drives are now quite affordable. The issue is hardware: need a lot of RAM, and a good video card, as well as a software package that is specifically tailored to working with LiDAR.

5. There needs to be a location to store the data, and a computer and software which is capable of working with the data.

Procedures

1. We need mass points and breaklines. Hydro breaklines are a must. Users of these products do not want to go without these layers. Field time is more efficient because of premapping prior to field work.

2. Deliverables were in individual quad format size. Mosaicing these into usable survey area sized format became a challenge as certain GIS software packages were memory intensive, and numerous iterations had to be performed to avoid errors and "crashes". In the future, I would request the data to be stitched together as a deliverable mosaic. IMG format tended to be easier to manage. Very pleased with the resolution for intended use, and pleased with the quality of the data.

3. DTM must be hydro enforced; buy the highest resolution/accuracy product you can afford, as it's always possible to generalize a product; just because you can make a 1 m DEM, doesn't mean you need it - different kinds of applications require different kinds of derivative data.

4. Tiling and naming conventions are important for large areas. Emphasize a tiling scheme based on USGS 7.5min quadrangles.

5. Minimize (but don't eliminate) the processing steps between the vendor delivering the product and the end-user. In other words know what product you envision utilizing and make sure you have the capacity to generate it within what is defined.

Contracting

1. Vendors are geared up for massive data processing - anticipate desired products and build into contracts. Must stay in close communication with vendor during processing - each project site differs. IDIQs work well for task-ordering from pre-qualified firms.

2. NRCS needs its own IDIQ LIDAR vehicle and support staff.

3. I feel we need an agency mechanism thru which standards are already set and contract examples readily available and accessible. Most of our money has come at the last minute with great difficulty in committing to a quality product....or even the expertise to pursue such a product. We had to rely on a lot of help from others within the agency who struggled thru much of the same process.

4. Be firm on timelines. Some initial local LIDAR projects had poor vendor QC which led to a lot of different versions of the data and a timeline that extended well beyond expectations.

5. Need to purchase a product that is ready to use. No processing should be required. We should use the lessons-learned from the DOQQ program. Today we receive a county ortho imagery in a SID or some other format that can be used without any processing. Note: DEM variables.

6. For Oregon soil survey activities only one project has been contracted to my knowledge. Our goal in this project was to 'fill in the holes' between others' project areas. That is, for soil survey activities we need seamless coverage. BLM, USFS, and state\county and various others' projects did not include intervening private land. NRCS was able to fill in several small gaps in order to achieve seamless coverage.
7. Flights should be based on area of need intersected with watershed boundaries and buffered slightly. Schedule photos to be taken and sync with flight.
8. If at all possible rely on non-federal cooperators to lead the proposals to minimize the reliance on local or National NRCS contracting (LIDAR only).

Appendix E – NRCS DEM Project Benefits

Tangible Benefits – Time and Cost Savings

In answering questions 57 and 64 that asked for explanations of tangible benefits from LiDAR and IFSAR, the following individual responses generally pertained to time and cost savings for NRCS.

LiDAR

1. With 500 plus soil scientist across the nation, it is far less costly to provide them with high quality data which they could use for modeling for years and can often save them a trip to the field or some remote location.
2. Cost reduction: an estimated 40% in efficiencies gained in engineering pre-design work (stated by our previous state engineer). Cost Avoidance: by using LiDAR first returns to model potential T&E species habitat the benefit is almost incalculable -- but estimated to be very high.
3. The key benefit may be reduced staff time in the field. One example would be the ability to make accurate HEL determinations from the office.
4. LIDAR is faster and less expensive than having the area surveyed.
5. Less or no surveying time for some types of projects; no need to send people to the field to perform surveys.
6. A time saver especially in the eqip planning stage.
7. Eliminates a large amount of surveying and returns a much higher coverage of design area. Cost savings/avoidance and better data for engineering design.
8. Saving staff time in the field and making us more efficient in areas of Engineering, Soil Survey and planning.
9. Workload associated with certain programs can be greatly reduced through measurement from LIDAR.
10. Increased efficiency in field work for Soil Survey.
11. More efficient use of staff by reducing time and cost for field work.
12. Replace much of the survey needed for planning and preliminary designs of projects.
13. Access to high res elevation data makes it possible to do more preliminary planning and design without an onsite survey.
14. Using LiDAR data reduces time required to draw contour lines on irrigation system design maps.

15. Soil Scientists can minimize their field time by using high resolution digital elevation data (HRDED), HRDED derivatives and orthophotos.

16. When adjusting soil slope polygons, time and travel is saved by not requiring travel to the field, and products are delivered faster.

17. Reduce field survey time for inventory and design, better planning to evaluate projects before survey time invested.

18. We reduce costs by decreasing the number of staff years it takes to complete a soil survey. Costs are avoided by eliminating the need to buy aerial photography for each survey area; flights can be less often because the data are better.

19. Less time spent in field attempting to determine if a project meets program criteria. Once this is identified, use of technology allows better planning for WRP.

20. In both of the Colorado projects, field survey work was avoided (because of the LiDAR data).

21. By spotting easement violations early, cost of correction and/or litigation will decrease.

22. Topographic surveys are no longer necessary. We can create proposals for landowners right from the office. We can do flow analysis, slope analysis, etc. because we have a seamless county wide data set.

23. LiDAR data will help target field soil scientist activities greatly reducing (and avoiding) costs associated with field work.

24. Targeting more efficient field work.

25. Time savings by being able to provide pre-field work costs estimates. Reduced time needed for field surveys.

26. Planning of projects is more reliable because of this data and therefore we can avoid costs that could arise due to improper planning caused by a lack of or use of poor data.

27. Better inventory of fields and less time spent getting the information (saving $).

28. Remote modeling for planning purposes as opposed to ground surveying.

29. Improved production due to reduced needs for field survey.

30. Reduction in cost per acre to define and delineate soil maps units for initial and update soil mapping. Reduction in field time and travel for initial layout of engineering practices.

31. We could have saved significant time for an interdisciplinary team had the LiDAR data been available to us at the beginning of the project. The team that field verified conditions could have been significantly smaller had we had the data and analysis earlier.

32. Better feasibility, planning and designs to avoid cost overruns. Partnerships with other agencies makes our money go further.

IFSAR

1. Better modeling in the office helps target field operations reducing associated costs.

2. Good, accurate elevation data can help us avoid surveying costs and costs of additional field work. Using this data in GIS modeling efforts to predict soil properties will be important as soil survey moves into updating existing soils data at MLRA scales.

3. Increased efficiency related to field work in Soil Survey; no need to send people to field to perform surveys.

4. IFSAR gives us the ability to do more mapping updates in the office, thus reducing the cost of going to the field.

5. Saves time from going out and surveying; reduce field survey time for inventory and design, better planning to evaluate projects before survey time invested.

6. The tangible benefits from IFSAR may be similar to the tangible benefits from LiDAR, but the relative advantages and disadvantages of these two technologies are very different.

7. Less expensive than LiDAR for arid areas with low veg where IFSAR is adequate.

8. Costs less than LiDAR.

Intangible Benefits – Improved Products and Services

In answering questions 59 and 66 that asked for explanations of intangible benefits from LiDAR and IFSAR, the following individual responses generally pertained to improved products and services in support of the NRCS mission.

LiDAR

1. Soil classifications are largely based on slopes; LiDAR is the most cost-effective way to map slopes and aspects. Improved workflow, more precise data means fewer mistakes and better service for our customers.

2. Better terrain models lead to more accurate line placement in soil survey.

3. More accurate designs, less time spent field checking and surveying.

4. We are developing highly accurate slope maps from LIDAR which will improve our soil survey product. With the current state of technology and the needs of our users such as farmers, ag industry, and conservationists, the NRCS soil maps are woefully inadequate.
5. Watershed modeling - allows much more accurate modeling and will model small project watersheds that our existing elevation data is too general for.
6. Improved workflow, more precise data means fewer mistakes and better service for our customers.
7. Supports the refinement of soils data and interpretations.
8. Accurate flood inundation zone delineation.
9. Greatly increased accuracy of soil mapunit delineations and more efficient use of personnel resources.
10. Improve accuracy of soils maps and soil landscape models.
11. Improve our products now in ways that were cost prohibitive before LIDAR data.
12. The cost for producing our product, at the same quality level as can be obtained using LiDAR, is prohibitive.
13. Increased accuracy and efficiency in producing soil survey products.
14. Enables users to complete tasks that are more quantitative and less "loose estimates."
15. Field work more focused directly on resource inventory and less on interpreting surfaces.
16. LiDAR can help reduce potential errors associated with restoration of wetlands, reduce unintended flooding of adjacent properties and help identify barriers to fish passage and potential nick-points in streams that can be problematic when structures are removed for restoration purposes.
17. Conservation structure design from LiDAR would be a tremendous benefit to the field offices.
18. Using [LiDAR] intensity imagery, there is a potential for identifying endangered species habitat, forage inventory, what the land will support as far as habitat, and precision farming.
19. Become a more productive partner in pre-fire management efforts.
20. Avoid significant archaeological features in project planning.
21. Immediate tax payer benefit of informed, enhanced assistance and reduction in future cost of government .

22. Flooding analysis, monetary savings as well as safety concerns.

23. RC&D works with rural communities and this is how it could benefit RC&D. We could offer a tremendous benefit to these communities. The small rural towns in Wyoming simply do not have the resources to gain LiDAR for their area, yet they have multiple concerns that have not been addressed and LiDAR could really assist with helping them in design and implementation.

24. Provides the ability of field staff to provide technical assistance to landowners with state of the art equipment. Also provides the ability to potentially show a landowner a 3-D model of what the practice will look like on the ground. Brings our staff into the current technological world.

25. Helps to visualize designs with modeling.

26. Public perception of our attention to detail and doing an excellent job is greatly improved. Higher level of credibility.

27. While we don't actually reduce staff due to time savings, we free them up for more technical issues than surveying. We improve the quality of our assistance to customers with better alternatives assessments. We create good will with other agencies and NGOs by sharing our data.

28. Better products can be developed from the more accurate elevations for conservation plans. Dam breach inundation areas will be more accurate. Resource inventory and assessment with slope data from LIDAR data will be more accurate allowing for better modeling of watersheds and targeting areas with more of a concern for water quality issues within the watershed.

29. Intangible benefits would come in dam rehab scenarios, soil survey update, evaluating resource concerns, and identifying areas for WRP.

30. Quantifiable results; improved reputation with customers. More rewarding work.

31. Better protection along river corridors from flooding.

32. More timely info, save on time to gather info.

33. Confirmation of data used by NRCS, other state and federal agencies, and private users of elevation data to satisfy conformity of public safety and legal issues.

34. Provide better accuracy for conservation planning and soil survey.

35. Improved perception of soil survey mapping by public (consistency and equity are improved)

36. Digital soil mapping and model development will be improved by more accurate and sensitive elevation data.

37. Delivery of more accurate information for all users of soil survey information to base their land use decisions.
38. Efficiency and quality improvements.
39. The improved accuracy of soil mapping leads to better interpretations as related to environmental protection, all of which are in support of NRCS and Soil Survey's mission.
40. Improved line placement on soil survey; more accurate dam breach modeling; faster and improved design of conservation practices and wetland restoration.
41. Economics can be more powerfully used.
42. This data would establish a basis for engineering plans that offer the development of alternative designs in a more timely manner for better customer service.
43. Provides information on land use and vegetative changes. Improved frequency and accuracy of data.
44. NRCS agency prides itself on technical abilities, therefore must have technology.
45. We can provide a much better product to our clientele than previously possible.
46. LiDAR data will enable us to produce better soil information. Better soil information affects decision-making and reporting, allows improved modeling\interpretations which in turn improve environmental protection, mission goals, and support of States.
47. Reduces State workload monitoring easements.
48. As our workload and budget increase, our employees are decreasing. This will help us to provide good service with the fewer people that we have.
49. It is important that we get folks at the field office level more exposure to LIDAR data and related products. The more they know what it is the more they will be able to envision ways that they could be using it in their planning efforts. NRCS has always been a leader in cartography and spatial data - LIDAR is a future component of both of these and we should be preparing our workforce to use it as it becomes more and more available in the public domain.
50. Excellent for flood analysis safety zones - proven in Story WY, Decision making capability available without needing to schedule an engineer, Accuracy is far superior to our current DEM's, would be used in EWP.
51. Improved, faster and more accurate analysis of aging dams and inundation. Faster, more accurate modeling of endangered species habitat. Improved mapping of large benefitted area landscapes. Smart web-based distribution methods will reduce state workloads.

52. Better landscape modeling to improve conservation planning for WHIP, WRP, and other habitat management programs.

IFSAR

1. Slope calculations for terrain mapping are more comprehensive than slope ranges per soil polygon.
2. Far better than USGS 10 and 30 meter DEMs.
3. We only have 30 meter DEMs for much of the state so IFSAR created hillshades and slope maps have been more accurate
4. In wetland determinations, IFSAR gives us another tool to relatively quickly determine the existence and extent of potential wetlands.
5. Creates a digital trail of data used for decision making.
6. Digital soil mapping and model development will be improved by more accurate and sensitive elevation data.
7. Provide higher quality soil survey products due to better detail for the intended scale of survey.
8. Better data leads to more accurate information that facilitates decision-making, better-interpretations leading to improvements for protection, mission goals, support, etc.
9. Better information will help NRCS better "help people help the land.“
10. The soil scientist community seems to have benefited the most from the NRCS IFSAR projects.
11. Improved quality of map unit design and delineation, resulting in an improved soil survey product.

Intangible Benefits – Improved Timeliness

In answering questions 59 and 66 that asked for explanations of intangible benefits from LiDAR and IFSAR, the following individual responses generally pertained to improved timeliness in delivery of NRCS products and services.

LiDAR

1. Ability to more quickly make planning decisions without delays from collecting data.
2. Faster, automated analysis and pre-design work.
3. Better data in the planning phase generally yields better and more timely products.

4. Better decision making in planning and products delivered to the customer... and time savings which would make us more efficient with our staff time.

5. LiDAR data would allow pre-planning of practices at the field office level; along with generation of estimated costs and quantities for the landowner based on data that has some level of confidence. Additionally, reduce time required for surveying; can survey limited area and tie the rest into the LiDAR data.

6. More efficient use of staff time; less staff time for surveys. Field information obtained sooner.

7. Soil survey models may help create a first draft soil survey faster and will help draw lines thus decreasing digitizing time.

8. Better remote sensing with less time in the field and travel.

9. Reduce time delays in spatial soils investigation by prioritizing specific areas in 7.2 million acre survey area.

10. Time savings by being able to provide pre-field work costs estimates. Reduced time needed for field surveys.

11. Ability to obtain dataset with much less personnel time than would have historically been required to cover the same area.

12. Reduction in staff time modifying and cancelling contracts.

IFSAR

1. Increase timeliness of finishing soil surveys in remote areas. Spend less time and equipment travelling to remote locations that may be analyzed in the office with high resolution elevation data. Provide more enhanced pre-mapping to shorten time spent in the field.

2. Reduced time to develop soil map unit delineations.

3. Reduce the amount of time for engineering assistance and allow us to better plan things and not have to involve the engineers as much.

4. More timely info, save on time to gather information.

5. Be able to make decisions earlier in the planning process.

Disadvantages of IFSAR

Appendix A of this DEM Whitepaper articulated the major advantages of IFSAR (nationwide availability and lower cost) and major disadvantages of IFSAR (lower accuracy and poor penetration of vegetation). In answering questions 59 and 66 that asked for explanations of intangible benefits from LiDAR and

IFSAR, the following individual responses pertained to such disadvantages of IFSAR in support of the NRCS mission in some areas.

1. NRCS should continue to be a leader in providing spatial data. LIDAR (not IFSAR) is the next generation of elevation data.

2. We have too many trees to use IFSAR effectively.

3. IFSAR does not meet the needs of Natural Resource Based Decision Making since there are some drawbacks to the model as compared to LIDAR.

Appendix F – NRCS Employee Recommendations

The following quotes are individual responses to question 71 that asked for specific recommendations on how NRCS should address diverse needs for elevation data from different NRCS Divisions and different states.

Need for Standardization

1. I would like to see each division at the national level responsible for determining their needs for all geospatial data including elevation. These needs should be determined based on current NRCS business practices that could be utilizing this technology. There is a finite number of business products that NRCS is responsible for developing and there should be national standards as to how they are developed. I would think that at a national level they could develop requirements for this elevation data to meet their standard. I think this should meet most of the agencies needs for elevation data. If the states need a higher accuracy product, then they need to be given the opportunity to express those needs to the national level in some kind of a forum to be acted upon.

2. Set up geographic categories to determine the minimum required levels of elevation data accuracy. Aggressively pursue multi-entity acquisitions efforts.

3. Minimum data standards; thorough metadata.

4. Develop a comprehensive minimum standard and allow states to buy-up to a higher specification if they are able. This way we at least have a base specification.

5. Standardize acquisition, processing, and accuracy assessment to improve and stabilize quality and save a LOT of money by not having every state dedicate staff to training and managing these data with uneven results.

6. We participate as a state in the project tracker through the efforts of Steve Nechero. LiDAR is an essential data layer for the work we do in NRCS. I expect that the soil survey and our conservation technical assistance would both benefit from the same elevation data standards, and this would represent the great majority of our applications. For more demanding engineering needs, I would suggest the use of more detailed spot sampling on the given watershed or work site involved. Seems that regional guidelines could relatively easily be established to suit the majority of users.

7. Develop standards for accuracy, deliverables but leave open for user-developed derivatives. Nested resolutions nationally are acceptable.

8. Continue to share information relevant to the status of development of standards. National standards, intent, directions assist with support of $'s from management in the states.

9. I think a product which reflects the maximum allowable vertical and horizontal accuracy for all divisions is a good starting point.

10. The better the accuracy of the data, the greater the number of applications it will have.

11. There is no point in standardizing data if the end result is not useful to half the users. Get the users the data they need to do the job! Provide PROCESSED elevation data in ready to use 'final-product' form (i.e. DEM).

12. Develop standards for use of elevation data in the initial and update mapping of soil surveys. Our national handbooks currently have little to no guidance on the appropriate use and quality assurance of these products and their derivatives. This results in spatial "models" of various quality and verification being used to support soil survey activities.

13. In some instances uses may be inappropriate but there are no standards for guidance. The current standards and procedures for mapping activities including soil concept development, documentation collection, and quality assurance are based on pre-ArcGIS methods and no longer reflect standard practices in the field to assist in mapping and ensuring quality of soil surveys.

14. Develop standards for use of elevation data in the initial and update mapping of soil surveys. Our national handbooks currently have little to no guidance on the appropriate use and quality assurance of these products and their derivatives. This results in spatial "models" of various quality and verification being used to support soil survey activities.

Need for Flexibility

1. There needs to be flexibility in approaching areas with intensive agriculture versus areas such as range land and forest land (order 2 versus order 3 mapping of soils).

2. Needs will vary according to uses and geographic and program areas.

3. NRCS should pursue various avenues in filing our needs nationally. As in most other topics, one size does not fit all. For example, if we had a vehicle to purchase LiDAR at a site specific scale for engineering type work, while having IFSAR available in a wholesale scale, it would fill most of our elevation needs in South Dakota NRCS.

4. Identify the diverse needs now and frequently in the future.

5. NRCS should remain flexible in the contracting process and data standards. If, for example, Oregon was forced to purchase future LiDAR through the USGS at a lower spec than the Oregon LiDAR Consortium, NRCS projects would be ineligible for inclusion in the Oregon LiDAR dataset and would eventually have to be reflown.

6. Allow flexibility in how the data is delivered or help identify tools that can convert the data to the format needed.

NRCS Acquisition Strategy

1. The biggest issue nationally and at the state level is that NRCS needs to realize that data acquisition needs to become part of a standard annual cost of doing business. States need a method to carry over funds year to year until they have enough to partner for imagery/elevation/data acquisitions. This includes a simplified contracting mechanism.

2. There needs to be a national contracting mechanism to make these projects happen easier.

3. Each state should make a plan for how to acquire the data and which types of resolutions/technology will be applicable for various parts of the state based on ownership and landuse type. Guidance could be provided by NCGC and work as an elevation data gathering location.

4. Fly LiDAR nationally, preferably at 1 meter, and write a general handbook for using the DEM within the Arc environment. There are so many options for elevation data that it is hard for people to sift through them, and it seems to happen that folks see 10 meter data and think it's "good enough" when really it yields no improvement in product in many cases.

5. Data should be public domain. Need dedicated funding rather than project-driven and year-end funding.

6. Buy the most accurate data you can afford. We don't fully understand all the benefits we will derive from LiDAR data in all the mission areas of NRCS.

7. Give us standards and a mechanism to commit end of year funds to LiDAR acquisition. Also be able to bank funds for larger project areas. Coordinate between states to encourage larger area acquisitions.

8. Several counties in Wisconsin have purchased LiDAR on their own. It would be nice to have a state wide acquisition in which the data is similar to what these counties are familiar with.

9. Obtain the best raw data available nationwide and process by priority based on use and need.

10. Think big by thinking small. That is, take the long view and do not collect low quality for the sake of expediency. Collect high resolution data at a high level of accuracy and precision. Elevation data can always be generalized for specific purposes, but it cannot be improved beyond the initial collection specs. Avoid buying coarser resolution elevation data that does not meet the needs of the engineering community.

NRCS Partnerships

1. Any acquisition of High resolution data should be shared with the USGS to help populate NED.

2. Foster partnerships through NDEP.

3. Work with the USGS, COE and BLM to secure coverage of LiDAR of the US just as coverage was done for topo paper maps.

4. Set up geographic categories to determine the minimum required levels of elevation data accuracy. Aggressively pursue multi-entity acquisitions efforts.

5. Partnerships for funding acquisition are essential.

NRCS Hardware and Software

1. We need bigger servers at the Field Office Service Centers. Ours is a 90 Meg. We don't even have room to store emails and normal files with all of the users we have. I backup to a portable drive instead of the server. I use IFSAR data from DVD's with no method to do major computing because of the lack of storage space. The NRCS needs to look at upgrading these servers from mega byte to terra byte size.

2. Provide data in various formats through a web server, where the user can identify his/her needs. Additionally, allows the user to select an area of interest and only download the needed data. Some data should be able to be processed on the fly and then downloaded into the software being used.

3. Fund the state offices to obtain adequate computer systems for storage and retrieval of LiDAR data to the field.

4. Need better functionality for delivery and storage for local use. Need enterprise licensing for application software.

5. LiDAR is nice to have, but datasets should only be put in the hands of specialists who can handle the data both intuitively, software and hardware wise. Higher resolution data will choke current computer systems in the field with TMI (too much info).

6. Get input from the field as much as possible. Need to expand and make available ArcGIS servers that run the models and deliver the derivative products so we can avoid the nightmare of delivering this massive amount of data.

7. The most immediate action item is to identify and acquire the proper hardware and software for all "power users" within the agency, so that we can take advantage of already existing LiDAR data.

NRCS Workforce Development

1. First priority would be to provide training for end users (e.g. GIS Specialists) about the nature and applications of various forms of elevation data. Increased familiarity should result in increased utilization of those resources.

2. Education and training in using LiDAR data effectively is a must. Investigate software options outside of ESRI for processing these data.

3. Develop workforce capable of realizing the potential of the products. Support tools that can be enhanced by HRED. Foster partnerships through NDEP.

4. Increase geospatial analyst and remote sensing training for NRCS professionals incorporating post-classroom quality development time and experimentation into the training plan/contract to ensure personnel become comfortable with software and techniques at some baseline level prior to integrating this knowledge into production. ESRI trainings (e.g. ArcGIS Spatial Analyst) suggest this time but it is not part of the training time budgeted by NRCS managers.

5. Establish GIS remote sensing work groups/teams based on MO areas with similar needs. This would encourage and enable GIS leaders in these MOs to pool their knowledge and work together to address needs specific to their regions.

6. Annual meetings of GIS work groups along with GIS focused personnel from MLRA soil survey offices would enhance knowledge transfer among the regions and offices.

Other

1. Continue these surveys periodically to re-assess needs as high intensity elevation data and their applications become more widely used and understood.

2. Just keep conservation planning in mind for the project and ask folks that run the model to test the data before releasing it to use.

3. I would like to see federal agencies use their leverage to push industry to develop devices that would capture both high-res terrain and bathymetric data. [Note: Today's topo/bathy LiDAR only works in relatively clear water].

Appendix G – NRCS Soil Survey Division DEM Requirements

By Tom D'Avello
USDA-NRCS

Background

Soil science is the science dealing with soils as a natural resource on the surface of the Earth. This includes soil formation, classification, mapping, and the physical, chemical, and biological properties of soils, and these properties in relation to the use and management of the soils.

The primary product of the Soil Survey Division is the soil survey. A soil survey describes the characteristics of the soils in a given area, classifies the soils according to a standard system of classification, plots the boundaries of the soils on a map, and makes predictions about the behavior of soils. The different uses of the soils and how the response of management affects them are considered. The information collected in a soil survey helps in the development of land-use plans and evaluates and predicts the effects of land use on the environment. Soil surveys were first authorized in the United States in 1896[3].

The properties of soil vary from place to place, but this variation is not random. Natural soil bodies are the result of the factors of soil formation: 1) climate and 2) living organisms acting on 3) parent material, with 4) topography/terrain exerting a modifying influence and with 5) time required for soil-forming processes to act. In general, soils are the same wherever all elements of the five factors are the same. This regularity permits prediction of the location of many different kinds of soil[3].

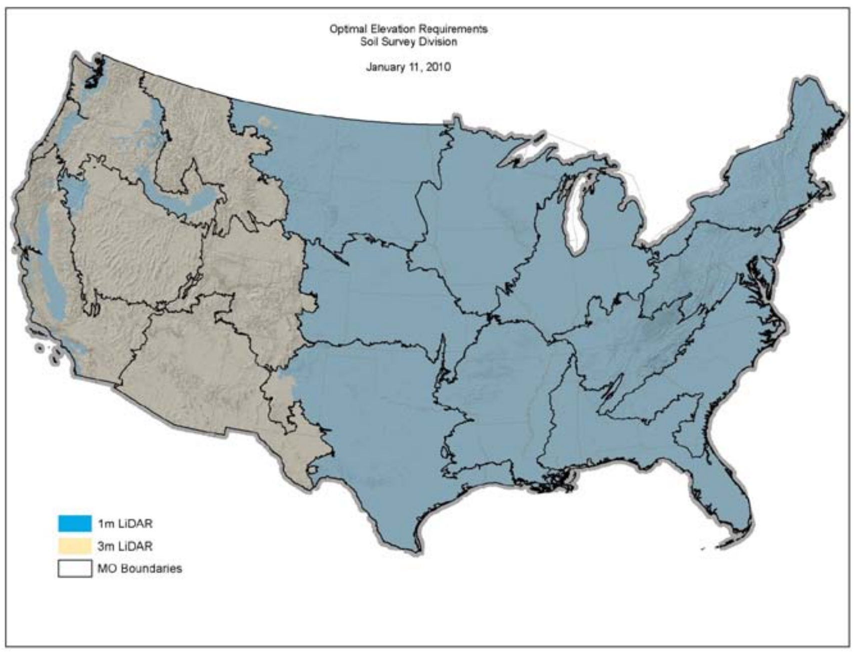
Traditionally, terrain features were mapped using stereo pairs of unrectified aerial photography and USGS Topographic Quadrangles. This was a subjective operation, dependent on the ability of the soil scientist to view in stereo. Today, geographic information systems and image processing software are used to analyze the geomorphology, terrain, vegetation, and climate to discover and map the patterns left on the landscape.

Soil Survey DEM Uses and Requirements

Terrain influences are the most universal factor determining the pattern of soil distribution. Software available today provides the potential for more objective determination of the terrain characteristics that are used to differentiate soils. Elevation presented as a raster array (gridded DEM) is the universal format used by soil scientists. Data delivered as a TIN or Terrain is converted to a raster format prior to use. Terrain features used by soil scientists include: elevation (Figures G.1 and G.2), hillshade (Figures G.3 and G.4), slope (Figure G.5), planform curvature[4] (Figure G.6), profile curvature[4] (Figure G.7), tangential curvature[4] (Figure G.8), flow accumulation (Figures G.9 and G.10), wetness index[7] (Figure G.11), relative position (Figure G.12), various landform classification schemes[1,2,6,8] (Figures G.13 and G.14), and sinks (Figures G.15 and G.16). Elevation is used to map flooding frequency and parent materials. Elevation is also used to estimate soil temperature, soil moisture regime and precipitation. Temperature and moisture regimes are part of the classification scheme used by soil scientists.

The usefulness of this data to the soil scientist is dependent on the horizontal resolution of the data. The required horizontal resolution is a function of the scale of mapping and the scale of features that require mapping. In general, smaller scale mapping, e.g. 1:62,500, can utilize data of coarser horizontal resolution. Areas with subtle landform features require finer horizontal resolution. At the minimum, horizontal positions should meet the National Standard for Spatial Data Accuracy (NSSDA) standards for the given scale of mapping. In general, soil scientists are concerned with relative vertical accuracy. However, data from sources like FEMA, USGS or state mapping agencies that are mapping elevation dependent features like floodplains, stream flow and geologic materials would require soil scientists have access to elevation data with vertical accuracy closer to absolute rather than relative accuracy.

Typically, soil scientists east of the Rocky Mountains require elevation data of 1m - 2m horizontal resolution for directly applicable use. Directly applicable means the data derivatives can be applied to the mapping process as-is. Coarser data, such as the 10m NED, have some use, but mostly as a general guide. The western states require elevation data at a resolution greater than the 10m NED. A particular circumstance in the western states is the need for multi-resolution datasets to accommodate the subtle landforms and more intense agricultural use that is common in the mountain valleys. For example, if 1m or 2m LiDAR were available, soil scientists may utilize the data as-is for the valleys, and resample the data to 5m resolution for use with rougher terrain. The process of resampling would be common throughout the Soil Survey Division to accommodate projects of varying areal extent and terrain. High resolution data would provide the flexibility to tailor the resolution to fit the user specified needs.



This map represents the optimal elevation requirements for soil scientists. The optimal set would provide data collected by common means, with the potential for merging into a seamless unified set in keeping with the USGS National Map that includes elevation and orthoimagery as foundation layers.

The specific requirements for LiDAR are best described in the USGS Base LiDAR Specification, Version 12[5].

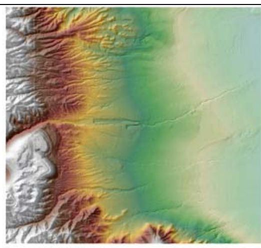


Fig. G.1) DEM, 10m NED. Elevation range: 2351m – 1357m (UT)

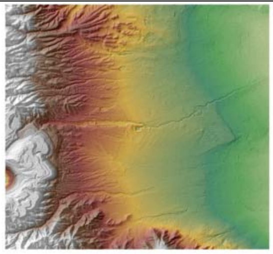


Fig. G.2) DEM, 3m LiDAR. Elevation range: 2360m – 1219m (UT)

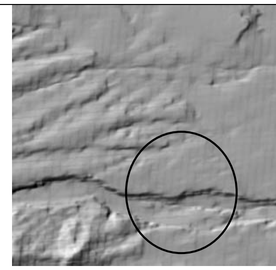


Fig. G.3) Hillshade, 10m NED. Diffuse feature definition (UT)

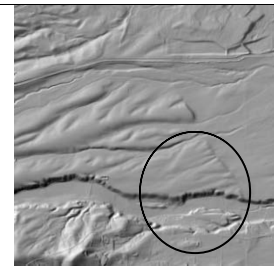


Fig. G.4) Hillshade, 3m LiDAR. More distinct feature definition (UT)

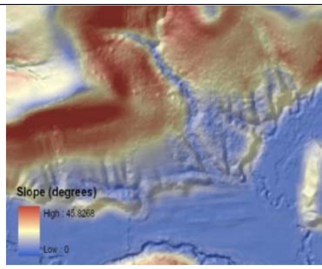


Fig. G.5) Slope, 3m LiDAR (OH)

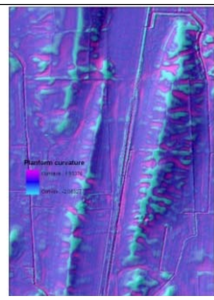


Fig. G.6) Planform curvature[4], 3m LiDAR (WI)

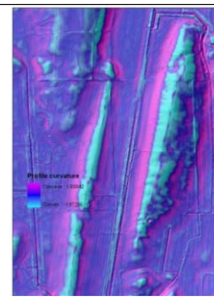


Fig.G. 7) Profile curvature[4], 3m LiDAR (WI)

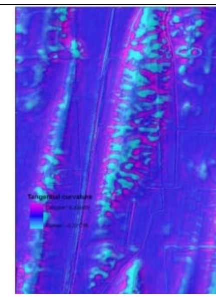


Fig. G.8) Tangential curvature[4], 3m LiDAR (WI)

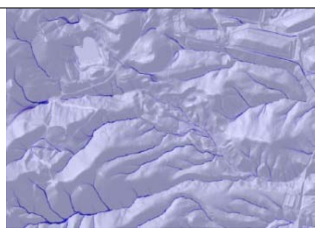


Fig.G. 9) Flow accumulation (multipaths), 3m LiDAR

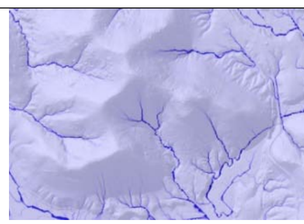


Fig. G.10) Flow accumulation (multipaths), 3m LiDAR. (OH)

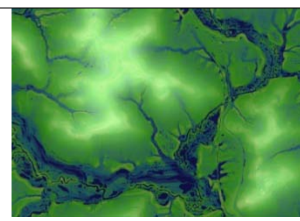


Fig. G.11) Wetness index[7], 3m LiDAR. (OH)

Fig. G.12) Relative position, 3m LiDAR (OH)

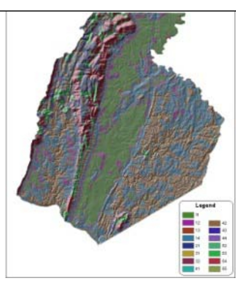


Fig. G.13) Hammond Landform classification[1,2,6] (MD)

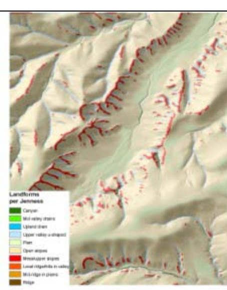


Fig. G.14) Jenness Landform classification[8], 3m LiDAR (UT)

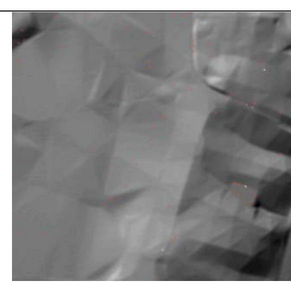


Fig. G.15) Automated Sink ID, 3m NED (WV)

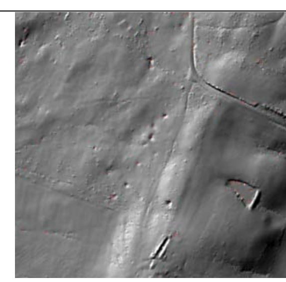


Fig. G.16) Automated Sink ID, 1m LiDAR (WV)

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Appendix H – USGS Base LiDAR Specification, v12

U.S. Geological Survey
National Geospatial Program
Base Lidar Specification

Version 12

The U.S. Geological Survey National Geospatial Program (NGP) has cooperated in the collection of numerous lidar datasets across the nation for a wide array of applications. These collections have used a variety of specifications and required a diverse set of products, resulting in many incompatible datasets and making cross-project analysis extremely difficult. The need for a single base specification, defining minimum collection parameters and a consistent set of deliverables, is apparent.

Beginning in late 2009, an increase in the rate of lidar data collection due to American Reinvestment and Recovery Act (ARRA) funding for The National Map makes it imperative that a single data specification be implemented to ensure consistency and improve data utility. Although the development of this specification was prompted by the ARRA stimulus funding, the specification is intended to remain durable beyond ARRA funded NGP projects.

The primary intent of this specification is to create consistency across all NGP funded lidar collections, in particular those undertaken in support of the National Elevation Dataset (NED). Unlike most other "lidar specs" which focus on the derived bare-earth DEM product, this specification places unprecedented emphasis on the handling of the source lidar point cloud data. This is to assure that the source data collected remains intact and viable to support the wide variety of non-DEM science and mapping applications that can benefit from lidar technology. In the absence of other comprehensive specifications or standards, it is hoped that this specification will, to the highest degree practical, be adopted by other USGS programs and disciplines, and by other Federal agencies.

Adherence to these minimum specifications ensures that bare-earth Digital Elevation Models (DEMs) derived from lidar data is suitable for ingestion into the NED (National Elevation Dataset) at the 1/9 arc-second resolution, and can be resampled for use in the 1/3 and 1 arc-second NED resolutions. It also ensures that the point cloud source data are handled in a consistent manner by all data providers and delivered to the USGS in clearly defined formats. This allows straight-forward ingest into CLICK (Center for Lidar Information, Coordination, and Knowledge) and simplifies subsequent use of the source data by the broader scientific community.

It should be stressed that this base specification defines minimum parameters. It is expected that local conditions in any given project area, specialized applications for the data, or the preferences of cooperators, may mandate more stringent requirements. The USGS encourages the collection of more detailed, accurate, or value-added data. A list of common options beyond the base specification is provided in Section V.

In addition, it is recognized that the USGS NGP also employs lidar technology for specialized scientific research and other projects whose requirements are incompatible with the provisions of this Specification. In such cases, and with properly documented justification supporting the need for the variance, waivers of any part or all of this Specification may be granted.

I. COLLECTION

1. Multiple Discrete Return, capable of at least 3 returns per pulse

   Note: Full waveform collection is both acceptable and encouraged; however, waveform data is regarded as supplemental information. The requirement for deriving and delivering multiple discrete returns remains in force in all cases.

2. Intensity values for each return.

3. Nominal **Pulse** Spacing (NPS) no greater than 2 meters; assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.

4. Collections designed to achieve the NPS through swath overlap or multiple passes are generally discouraged. Such collections may be permitted in special cases, with prior approval.

5. Data Voids [areas => $(4*NPS)^2$, measured using 1^{st}-returns only] within a single swath are not acceptable, except:

   - where caused by water bodies
   - where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing.
   - where appropriately filled-in by another swath

6. The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the data set:

   - A regular grid, with cell size equal to the design NPS will be laid over the data.
   - At least 90% of the cells in the grid shall contain at least 1 lidar point.
   - Clustering will be tested against the 1^{st} return only data
   - Acceptable data voids identified previously in this specification are excluded.

   Note: This requirement may be relaxed in areas of significant relief where it is impractical to maintain a consistent NPS.

7. Preferred Scan Angle (Total FOV) should not exceed 40°. USGS quality assurance on collections performed using scan angles wider than 34° will be particularly rigorous in the edge-of-swath areas. Horizontal and vertical accuracy shall remain within the requirements as specified below.

8. Vertical Accuracy:

*Note: The term "accuracy" has commonly been used in the industry to refer to the tested $RMSE_Z$ of the lidar data. Technically, this is improper usage: NSSDA Accuracy is defined as: the 95% confidence level, equal to ($RMSE_Z$ * 1.96) in a set of errors assumed to be normally distributed. In keeping with common usage to reduce confusion, this Specification's use of the term "accuracy" is indicative of the RMSE value and will be annotated as such. See the FEMA "Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A", Section A.3.2 for additional information.*

NSSDA $RMSE_Z$ = 15cm (NSSDA $Accuracy_Z$ 95% = 30cm) or better; assessment procedures to comply with FEMA guidelines.

Note: This requirement may be relaxed to NSSDA $RMSE_Z$ = 18.5cm (NSSDA $Accuracy_Z$ 95% = 37cm) in cases:

- *where there exists a demonstrable increase in cost to obtain 15cm $RMSE_Z$ accuracy over 18.5cm $RMSE_Z$ accuracy.*
- *where the 18.5cm $RMSE_Z$ specification is needed to conform to previously contracted phases of a single larger overall collection effort, i.e., multi-year statewide collections, etc.*
- *where the USGS agrees that it is reasonable and in the best interest of all stakeholders to use the 18.5cm $RMSE_Z$ specification.*

9. Relative accuracy of 5cm $RMSE_Z$ or better; assessment to be made swath-to-swath and within single swaths.

Note: This requirement will be relaxed to 6cm $RMSE_Z$ on collections using the 18.5cm $RMSE_Z$ overall specification.

10. Flightline overlap 20% or greater, as required to ensure there are no data gaps between the usable portions of the swaths. Collections in high relief terrain are expected to require greater overlap. Any data with gaps between the geometrically usable portions of the swaths will be rejected.

11. Collection Area: Defined Project Area, buffered by a minimum of 200*NPS.

Note: For collections in coastal areas, this requirement may be relaxed on seaward boundaries to eliminate needless collection over water.

12. Collection Conditions:

- Atmospheric: Cloud and fog-free between the aircraft and ground
- Ground:
    - Snow free; very light, undrifted snow may be acceptable in special cases, with prior approval.
    - No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation.

- Vegetation: Leaf-off is preferred, however:
  - As numerous factors will affect vegetative condition at the time of any collection, the USGS NGP only requires that penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable for incorporation into the 1/9 (3-meter) NED.
  - Collections for specific scientific research projects may be exempted from this requirement, with prior approval.

II. DATA PROCESSING and HANDLING

1. All processing should be carried out with the understanding that all point deliverables are required to be in fully compliant LAS format, v1.2 or v1.3. Data producers are encouraged to review the LAS specification in detail.

2. If full waveform data is collected, delivery of the waveform packets is required. LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.

   GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus $1*10^9$. See the LAS Specification for more detail.

3. The USGS preferred Spatial Reference System for the Conterminous United States (CONUS) is: UTM, NAD83, Meters; NAVD88, Meters. Data should reference the most recent Geoid model approved by the NGS. Each discrete project is to be processed using the predominant UTM zone for the overall collection area. State Plane Coordinate Reference Systems that have been accepted by the European Petroleum Survey Group (EPSG) and that are recognized by ESRI GIS software may be used by prior agreement with the USGS. Alternative projected coordinate systems for collections in Alaska, Hawaii, and other Outside Conterminous United States (OCONUS) areas must be approved by the USGS prior to collection.

4. All references to the Unit of Measure "Feet" or "Foot" must specify either "International" or "U.S. Survey"

5. Long swaths (those which result in a LAS file larger than 2GB) should be split into segments. Each segment will thenceforth be regarded as a unique swath. Other swath segmentation criteria may be acceptable, with prior approval.

6. Point Families (multiple return "children" of a single "parent" pulse) shall be maintained intact through all processing prior to tiling. Multiple returns from a given pulse shall be stored in sequential order.

7. Each swath will be assigned a unique File Source ID. The Point Source ID field shall be set equal to the File Source ID prior to any processing of the data. See the LAS Specification.

8. All collected swaths are to be delivered. This includes calibration swaths and cross-ties. All collected points are to be delivered. No points are to be deleted from the swath LAS files. This in no way requires or implies that calibration swath data are to be included in product generation. Excepted from this are extraneous data (aircraft turns, transit between the collection area and airport, transit between fill-in areas, etc.) that may be permanently removed.

9. Within each LAS file, points from a given swath shall be stored together and in their collected order.

10. Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable are to be identified using the "Withheld" flag, as defined in the LAS specification.

    - This applies primarily to points which are identified during pre-processing or through automated post-processing routines.

    - "Noise points" identified during manual Classification and Quality Assurance/Quality Control (QA/QC) may be assigned the standard LAS classification value (class value = 7), regardless of whether the noise is "low" or "high" relative to the ground surface.

11. The Overlap Classification (class value = 12) shall not be used. ALL points not tagged as "Withheld" are to be classified.

12. If overlap points are required to be differentiated for processing, they are to be tagged using Bit:0 of the User Data byte, as defined in the LAS specification. (SET=Overlap). If so required, this tag is to be included in the delivered point data.

13. Positional Accuracy Validation: The absolute and relative accuracy of the data, both horizontal and vertical, relative to known control, shall be verified prior to classification and subsequent product development. A detailed report of this validation is a required deliverable.

14. Classification Accuracy: It is expected that due diligence in the classification process will produce data that meets the following test:

    > Within any 1km x 1km area, no more than 2% of points will possess a demonstrably erroneous classification value. This includes points in Classes 0 and 1 that should correctly be included in a different Class required by the contract.

    Note: This requirement may be relaxed to accommodate collections in areas where the USGS agrees classification to be difficult.

15. Tiles:

    Note: This section assumes a projected coordinate reference system.

    - A single non-overlapped tiling scheme will be established and agreed upon by the data producer and the USGS prior to collection. This scheme will be used for **all** tiled deliverables.

- Tile size must be an integer multiple of the cell size of raster deliverables.
- Tiles must be sized using the same units as the coordinate system of the data.
- Tiled deliverables shall conform to the tiling scheme, without added overlap.
- Tiled deliverables shall edge-match seamlessly in both the horizontal and vertical.

III. HYDRO-FLATTENING REQUIREMENTS

Note: Please refer to Section VI for reference information on hydro-flattening.

1. Inland Ponds and Lakes:
   - ~2-acre or greater surface area (~350' diameter for a round pond)
   - Flat and level water bodies (single elevation for every bank vertex defining a given water body).
   - The entire water surface edge must be at or just below the immediately surrounding terrain.
   - Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.
2. Inland Streams and Rivers:
   - 100' **nominal** width: This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100' for short segments. Data producers should use their best professional judgment.
   - Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
   - The entire water surface edge must be at or just below the immediately surrounding terrain.
   - Streams should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should **not** break at bridges. Bridges should be removed from DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.
3. Non-Tidal Boundary Waters:
   - Represented only as an edge or edges within the project area; collection does not include the opposing shore.
   - The entire water surface edge must be at or below the immediately surrounding terrain.

- The elevation along the edge or edges should behave consistently throughout the project. May be a single elevation (i.e., lake) or gradient (i.e., river), as appropriate.

4. Tidal Waters:

   - Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations.

   - Tidal variations over the course of a collection, and between different collections, will result in discontinuities along shorelines. This is considered normal and these "anomalies" should be retained. The final DEM should represent as much ground as the collected data permits.

   - Variations in water surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this requires either the removal of ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts the unavoidable irregularities in water surface.

   - Scientific research projects in coastal areas often have very specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.

Cooperating partners may require collection and integration of single-line streams within their lidar projects. While the USGS does not require these breaklines be collected or integrated, it does require that if used and incorporated into the DEMs the following guidelines are met:

1. All vertices along single-line stream breaklines are at or below the immediately surrounding terrain.
2. Single-line stream breaklines are not to be used to introduce cuts into the DEM at road crossings (culverts), dams, or other such features. This is hydro-enforcement and as discussed in Section VI, creates a non-traditional DEM that is not suitable for integration into the NED.
3. All breaklines used to modify the surface are to be delivered to the USGS with the DEMs.

The USGS does not require any particular process or methodology be used for breakline collection, extraction, or integration. However, the following general guidelines must be adhered to:

1. Bare-earth lidar points that are in close proximity breaklines should be excluded from the DEM generation process. This is analogous to the removal of masspoints for the same reason in a traditional photogrammetrically compiled DTM.

The proximity threshold for reclassification as "Ignored Ground" is at the discretion of the data producer, but in general should be approximately equal to the NPS.

2. These points are to be retained in the delivered lidar point dataset and shall be reclassified as "Ignored Ground" (class value = 10) so that they may be subsequently identified.

3. Delivered data must be sufficient for the USGS to effectively recreate the delivered DEMs using the lidar points and breaklines without significant further editing.

IV. DELIVERABLES

The USGS shall have unrestricted rights to all delivered data and reports, which will be placed in the public domain. This specification places no restrictions on the data provider's rights to resell data or derivative products as they see fit.

1. Metadata

- Collection Report detailing mission planning and flight logs.
- Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
- Processing Report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening *(see Sections III and VI for more information on hydro-flattening)*.
- QA/QC Reports (detailing the analysis, accuracy assessment and validation of:
  - The point data (absolute, within swath, and between swath)
  - The bare-earth surface (absolute)
  - Other optional deliverables as appropriate
- Control and Calibration points: All control and reference points used to calibrate, control, process, and validate the lidar point data or any derivative products are to be delivered.
- Geo-referenced, digital spatial representation of the precise extents of each delivered dataset. This should reflect the extents of the actual lidar source or derived product data, exclusive of Triangular Irregular Network (TIN) artifacts or raster NODATA areas. A union of tile boundaries or minimum bounding rectangle is not acceptable. ESRI Polygon shapefile is preferred.
- Product metadata (FGDC compliant, XML format metadata). One file for each:
  - Project
  - Lift

- Tiled deliverable product group (classified point data, bare-earth DEMs, breaklines, etc.). Metadata files for individual tiles are not required.

2. Raw Point Cloud

- Fully compliant LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in all LAS file headers
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return.
- Intensity values (rescaled to 8-bit)
- Full swaths, all collected points to be delivered.
- 1 file per swath, 1 swath per file, file size not to exceed 2GB, as described in Section II, Paragraph 5.

3. Classified Point Cloud

Note: Delivery of a classified point cloud is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- Fully compliant LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in LAS header
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return.
- Intensity values (rescaled to 8-bit)
- Tiled delivery, without overlap (tiling scheme TBD)
- Classification Scheme (minimum):

Code	Description
1	Processed, but unclassified
2	Bare-earth ground
7	Noise (low or high, manually identified, if needed)
9	Water
10	Ignored Ground (Breakline Proximity)

Note: Class 7, Noise, is included as a convenience for the data producer. It is not required that all "noise" be assigned to Class 7.

Note: Class 10, Ignored Ground, is for points previously classified as bare-earth but whose proximity to a subsequently added breakline requires that it be excluded during Digital Elevation Model (DEM) generation.

4. **Bare Earth Surface (Raster DEM)**

Note: Delivery of a bare-earth DEM is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- Cell Size no greater than 3 meters or 10 feet, and no less than the design Nominal Pulse Spacing (NPS).
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred)
- Georeference information shall be included in raster file
- Tiled delivery, without overlap
- DEM tiles will show no edge artifacts or mismatch
- Void areas (i.e., areas outside the project boundary but within the tiling scheme) shall be coded using a unique "NODATA" value. This value shall be identified in the appropriate location within the file header.
- Vertical Accuracy ($RMSE_Z$) of the bare earth surface is to be assessed using the methods described in the FEMA "Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A", Section A.8.5 paragraph 1, Section A.8.6.1, and Section A.8.6.2 (substituting the contracted vertical accuracy requirements ($RMSE_Z$) for those listed in the FEMA document). All QA/QC analysis materials and results are to be delivered to the USGS.
- Depressions (sinks), natural or man-made, are not to be filled (as in hydro-conditioning and hydro-enforcement).
- Water Bodies (ponds and lakes), wide streams and rivers ("double-line"), and other non-tidal water bodies as defined in Section III are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~2 acre in area (equivalent to a round pond ~350' in diameter), to all streams that are nominally wider than 100', and to all non-tidal boundary waters bordering the project area regardless of size. The methodology used for hydro-flattening is at the discretion of the data producer.

Note: Please refer to the Sections III and VI for detailed discussions of hydro-flattening.

5. Breaklines

Note: Delivery of the breaklines used in hydro-flattening is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement. If hydro-flattening is achieved through other means, this section may not apply.

- All breaklines developed for use in hydro-flattening shall be delivered as an ESRI feature class (PolylineZ or PolygonZ format, as appropriate to the type of feature represented and the methodology used by the data producer). Shapefile is preferred.
- Each feature class or shapefile will include properly formatted and accurate georeference information in the standard location. Shapefiles must include the companion .prj file.
- Breakline elevations will use the same coordinate reference system (horizontal and vertical) and units as the lidar point delivery.
- Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. Tiled deliveries must edge-match seamlessly in both the horizontal and vertical.

APPENDIX 1

COMMON BUY-UP OPTIONS

1. Independent 3rd-Party QA/QC by another AE Contractor (encouraged)
2. Higher NPS
   - 1.4m, 1.0m, 0.7m, etc…
3. Increased Vertical Accuracy ($RMSE_Z$)
   - 12cm, 9.25cm, etc…
4. Additional Environmental Constraints
   - Tidal coordination, flood stages, crop/plant growth cycles, etc.
   - Shorelines corrected for tidal variations within a collection
5. Top-of Canopy (First-Return) Raster Surface (tiled). Raster of the highest return on each cell is preferred.
6. Intensity Images (8-bit gray scale, tiled)
7. Detailed Classification (additional classes):

Code	Description
3	Low vegetation
4	Medium vegetation (use for single vegetation class)
5	High vegetation
6	Buildings, bridges, other man-made structures
n	additional Class(es) as agreed upon in advance

8. Breaklines (PolylineZ and PolygonZ) for single-line hydrographic features (narrow streams not collected as double-line), including appropriate integration into delivered DEMs
9. Breaklines (PolylineZ and PolygonZ) for other features (TBD), including appropriate integration into delivered DEMs
10. Extracted Buildings (PolygonZ): Footprints with maximum elevation and/or height above ground as an attribute.
11. Other products as defined by requirements and agreed upon in advance of funding commitment.

APPENDIX 2

HYDRO-FLATTENING REFERENCE

The subject of modifications to lidar-based DEMs is somewhat new, and although authoritative references are available, there remains significant variation in the understanding of the topic across the industry. The following material was developed to provide a definitive reference on the subject only as it relates to the creation of DEMs intended to be integrated into the USGS NED. The information presented here is not meant to supplant other reference materials and it should not be considered authoritative beyond its intended scope.

The term "**hydro-flattening**" is also new, coined for this document and to convey our specific needs. It is not, at this time, a known or accepted term across the industry. It is our hope that its use and acceptance will expand beyond the USGS with the assistance of other industry leaders.

Hydro-flattening of DEMs is predominantly accomplished through the use of breaklines, and this method is considered standard. Although other techniques may exist to achieve similar results, this section assumes the use of breaklines. The USGS does not require the use of any specific technique.

The Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition (Maune *et al.*, 2007) provides the following definitions related to the adjustment of DEM surfaces for hydrologic analyses:

1. **Hydrologically-Conditioned (Hydro-Conditioned)** – Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas "hydrologically-enforced" is relevant to drainage features that are generally mapped, "hydrologically-conditioned" is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relationships/links among basins/catchments can be known for large areas. This term is specifically used when describing EDNA (see Chapter 4), the dataset of NED derivatives made specifically for hydrologic modeling purposes.
2. **Hydrologically-Enforced (Hydro-Enforced)** – Processing of mapped water bodies so that lakes and reservoirs are level and so that streams flow downhill. For example, a DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also utilize breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features. Shore breaklines for streams would be 3-D breaklines

> with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout. See figures 1.21 through 1.24. See also the definition for "hydrologically-conditioned" which has a slightly different meaning.

While these are important and useful modifications, they both result in surfaces that differ significantly from a traditional DEM. A "hydro-conditioned" surface has had its sinks filled and may have had its water bodies flattened. This is necessary for correct flow modeling within and across large drainage basins. "Hydro-enforcement" extends this conditioning by requiring water bodies be leveled and streams flattened with the appropriate downhill gradient, and also by cutting through road crossings over streams (culvert locations) to allow a continuous flow path for water within the drainage. Both treatments result in a surface on which water behaves as it physically does in the real world, and both are invaluable for specific types of hydraulic and hydrologic (H&H) modeling activities. Neither of these treatments is typical of a traditional DEM surface.

A traditional DEM such as the NED, on the other hand, attempts to represent the ground surface more the way a bird, or person in an airplane, sees it. On this surface, natural depressions exist, and road fills create apparent sinks because the road fill and surface is depicted without regard to the culvert beneath. Bridges, it should be noted, are removed in most all types of DEMs because they are man-made structures that have been added to the landscape.

Note: DEMs developed solely for orthophoto production may include bridges, as their presence can prevent the "smearing" of structures and reduce the amount of post-production correction of the final orthophoto. These are "special use DEMs" and are not relevant to this discussion.

For years, raster Digital Elevation Models (DEMs), have been created from a Digital Surface Model (DSM) of masspoints and breaklines, which in turn were created through photogrammetric compilation from stereo imagery. Photogrammetric DSMs inherently contain breaklines defining the edges of water bodies, coastlines, single-line streams, and double-line streams and rivers, as well as numerous other surface features.

Lidar technology, however, does not inherently collect the breaklines necessary to produce traditional DEMs. Breaklines have to be developed separately through a variety of techniques, and either used with the lidar points in the generation of the DEM, or applied as a correction to DEMs generated without breaklines.

In order to maintain the consistent character of the NED as a traditional DEM, the USGS NGP requires that all DEMs delivered have their inland water bodies flattened. This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset; only those breaklines necessary to ensure that the conditions defined in Section III exist in the final DEM.

APPENDIX 3

REFERENCES

Maune, D.F., 2007. Definitions, in *Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2^{nd} Edition* (D.F. Maune, editor), American Society for Photogrammetry and Remote Sensing, Bethesda, MD pp. 550-551

National Digital Elevation Program, 2004. *Guidelines for Digital Elevation Data—Version 1*, 93 p., available online at: http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf (last date accessed: 29 September 2009)

FEMA, 2003. *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying,* 59 p., available online at: http://www.fema.gov/library/viewRecord.do?id=2206 (last date accessed 29 September 2009)

USGS NED Website: www.ned.usgs.gov

USGS CLICK Website: www. lidar.cr.usgs.gov

Final Page