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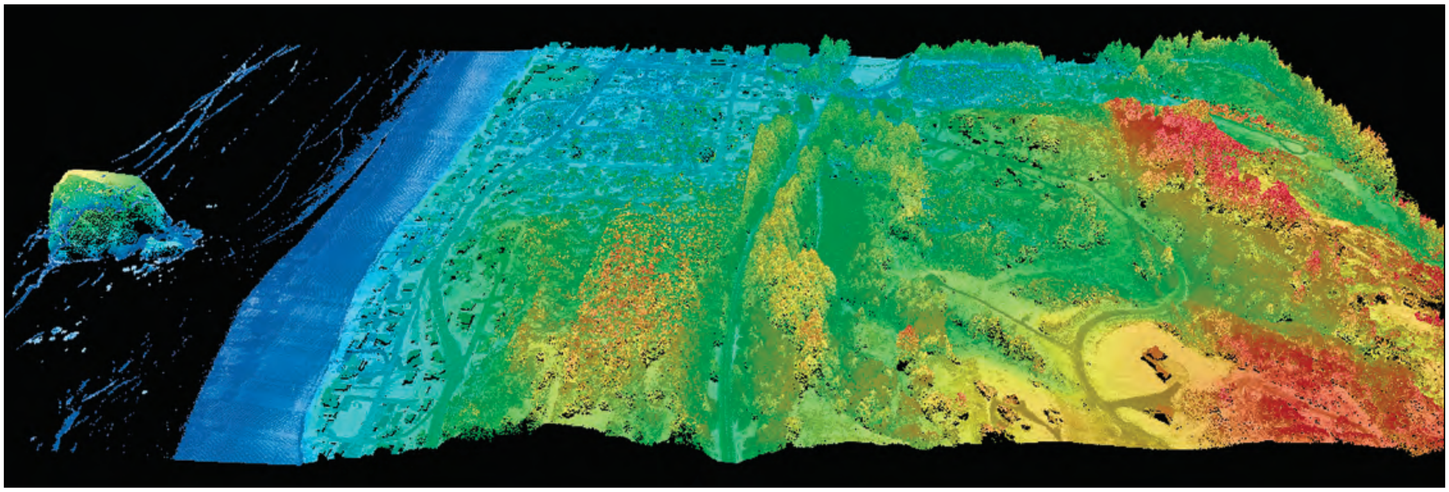
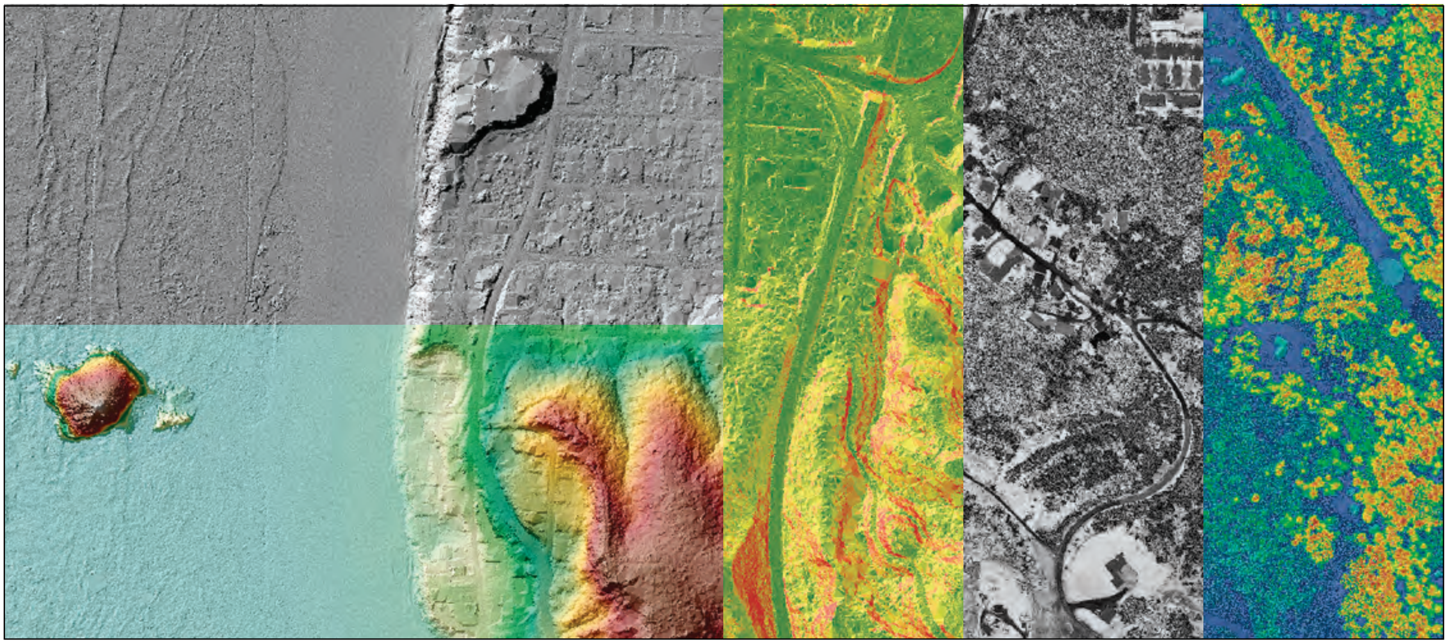
The 3D Elevation Program Initiative—A Call for Action





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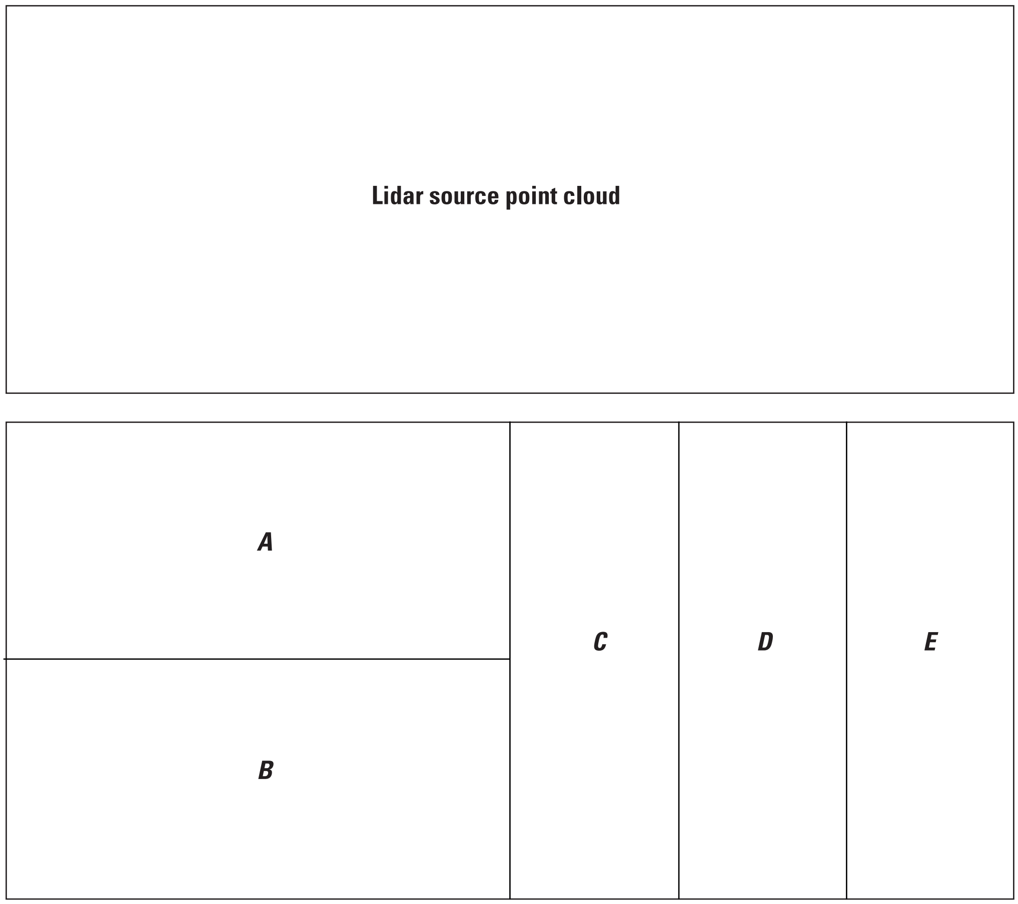

Front cover:

Top: A representative image of a lidar source point cloud. The data were collected by an airborne lidar instrument over Cannon Beach, Oregon, in 2008–2009. The Oregon Department of Geology and Mineral Industries (DOGAMI) acquired the data in partnership with multiple other organizations. When the 3D Elevation Program (3DEP) is fully realized, similar high-resolution lidar (light detection and ranging) data will be available for the entire conterminous United States and Hawaii. They will support many applications, including flood risk management, hazard mitigation, and natural resource management. The colors in this point cloud indicate elevation, from low (blue) to high (red).

Bottom: Examples of top-down views of a suite of derivative products that all were generated from the above lidar point cloud by the U.S. Geological Survey. North is at the top of the page. ***A*, Hillshade (shaded-relief) model**, which is used for visualizing the terrain. ***B*, Digital elevation model (bare-earth DEM)**, which is used for general topographic analysis and mapping. Lower areas are shown as green, and higher areas are shown as brown. The brown area at left is a feature called Haystack Rock. The DEM and hillshade model are both derived from the lidar classified point cloud by filtering points and interpolating between points. ***C*, Slope (bare-earth) model**, showing the vertical change from one bare-earth elevation cell to its neighbor. Steep slopes are shown as red, and flat areas are shown as green. ***D*, Laser-intensity model**, showing the strength of the laser signal returned from a lidar pulse. Laser-intensity models allow compilation of breaklines, such as ridges and shorelines. The curving line represents a road. ***E*, Height-above-ground model**, showing the vertical difference between the highest nonground return and the ground return. Tree-canopy heights and building footprints and their associated heights can easily be extracted from this derivative. The dark-blue line represents an area of no trees, where a powerline has been cut through.

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Foreword

U.S. Geological Survey (USGS) employees are often on the front line when a natural disaster occurs, and we are well known for providing leading-edge science to help prepare the Nation for earthquakes, floods, landslides, hurricanes, and other natural hazards our citizens face. Light detection and ranging (lidar) data and interferometric synthetic aperture radar (ifsar) data have become preferred technologies to support USGS science when we need to better understand the terrain. The value of lidar data was never more apparent than when the devastating landslide occurred in Oso, Washington, catastrophic floods raged through Colorado's Front Range, and Hurricane Sandy slammed into the Atlantic coast of the northeastern United States. Elevation models created from lidar data were used to determine the extent of damage and are helping today to support ongoing recovery activities in all three of these areas. The USGS National Geospatial Program supports multiagency partnerships to collect baseline lidar data. However, critically important high-resolution lidar data are not always available to address the need. If we are to better prepare the Nation for disasters and provide a baseline of high-quality three-dimensional (3D) elevation data to support critical resource and economic decisions, then a national program to collect these data for the entire country is essential.

The 3D Elevation Program (3DEP) initiative is a response to the National Enhanced Elevation Assessment (NEEA) study findings that identified more than 600 requirements for enhanced elevation data to address mission-critical information needs of Federal agencies and State, Tribal, and local governments. If fully funded, it is estimated that 3DEP could return more than $690 million annually in new benefits to the private sector and to citizens through improved government program services. Today, about $50 million is invested annually in lidar and ifsar data by all public agencies, and our elevation data inventory shows that only 4 percent of the conterminous United States, Hawaii, and U.S. territories has lidar data that meet the quality levels needed. Full implementation of 3DEP, which would require an additional $96 million annually from all funding sources, is conservatively estimated to result in a nearly 5:1 return on investment. In addition, these data would save lives, help our economy, and improve our environment through informed decisions.

The 3DEP initiative presents a unique opportunity to increase collaboration among all levels of government, to leverage the services and expertise of private sector mapping firms that acquire the data, and to create jobs now and in the future. When partners work together, they can achieve efficiencies and lower costs so that 3DEP can become a reality and our Nation will be better prepared when natural disasters hit. When 3D elevation data are available to everyone, innovations will occur in forest resource management, alternative energy, agriculture, and other industries for years to come.

Suzette M. Kimball
Acting Director

Acknowledgments

The 3D Elevation Program initiative is the product of thousands of hours of tireless work by many individuals both within the U.S. Geological Survey (USGS) and among our partner Federal, State, and professional organizations. The authors wish to acknowledge additional contributions made by David Brostuen, Robert Dollison, Michael Domaratz, James Mauck, and Gregory Snyder (all of the USGS). Dr. Dave Maune, of Dewberry, was instrumental in conducting the original National Enhanced Elevation Assessment (NEEA) study. Dr. Maune has often characterized the study as a great example of the private sector and government working in partnership. Working together in partnership has been the theme of the entire program and it is with a sense of optimism that the authors put forth the plan described in this call to action. The 3D Elevation Program was endorsed by or received letters of budget support from the American Society for Photogrammetry and Remote Sensing (ASPRS), the Association of American State Geologists (AASG), the Association of State Floodplain Managers (ASFPM), the Coalition of Geospatial Organizations (COGO), the Management Association for Private Photogrammetric Surveyors (MAPPS), the National Geospatial Advisory Committee (NGAC), the National Society of Professional Surveyors (NSPS), and the National States Geographic Information Council (NSGIC).

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
square meter (m^2)	10.76	square foot (ft^2)

Abbreviations

2D	two dimensional
3D	three dimensional
3DEP	3D Elevation Program
AASG	Association of American State Geologists
ASFPM	Association of State Floodplain Managers
ASPRS	American Society for Photogrammetry and Remote Sensing
BAA	Broad Agency Announcement
CAD	computer-aided design
CEGIS	Center of Excellence for Geospatial Information Science (USGS)
COGO	Coalition of Geospatial Organizations
CoNED	Coastal National Elevation Database
CONUS	conterminous United States
CRS	coordinate reference system
DEM	digital elevation model
DOI	U.S. Department of the Interior
DSM	digital surface model
DTM	digital terrain model
EROS	Earth Resources Observation and Science
FACA	Federal Advisory Committee Act
FGDC	Federal Geographic Data Committee
FY	fiscal year
GAO	U.S. Government Accountability Office

GIS	geographic information system
GPSC	geospatial products and services contract
GRAV–D	Gravity for the Redefinition of the American Vertical Datum
HPC	high-performance computing
IDIQ	indefinite delivery, indefinite quantity
ifsar	interferometric synthetic aperture radar
IWG–OCM	Interagency Working Group on Ocean and Coastal Mapping
K–12	kindergarten through twelfth grade
lidar	light detection and ranging
MAPPS	Management Association for Private Photogrammetric Surveyors
NCMS	National Coastal Mapping Strategy
NDEP	National Digital Elevation Program
NED	National Elevation Dataset
NEEA	National Enhanced Elevation Assessment
NGAC	National Geospatial Advisory Committee
NGDA	National Geospatial Data Asset
NGP	National Geospatial Program (USGS)
NGS	National Geodetic Survey (NOAA)
NGTOC	National Geospatial Technical Operations Center (USGS)
NOAA	National Oceanic and Atmospheric Administration
NPD	nominal pulse density
NPS	nominal pulse spacing
NSGIC	National States Geographic Information Council
NSPS	National Society of Professional Surveyors
NSRS	National Spatial Reference System
OMB	Office of Management and Budget (U.S.)
OSTP	Office of Science and Technology Policy
QA/QC	quality assurance/quality control
QBS	qualifications-based selection
QC	quality control
QL	quality level
$RMSD_Z$	root mean square difference in the z (elevation) dimension
$RMSE_Z$	root mean square error in the z (elevation) dimension
TBD	to be determined
TIN	triangulated irregular network
USGS	U.S. Geological Survey
USIEI	United States Interagency Elevation Inventory
WCS	Web Coverage Service

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Abstract

The 3D Elevation Program (3DEP) initiative is accelerating the rate of three-dimensional (3D) elevation data collection in response to a call for action to address a wide range of urgent needs nationwide. It began in 2012 with the recommendation to collect (1) high-quality light detection and ranging (lidar) data for the conterminous United States (CONUS), Hawaii, and the U.S. territories and (2) interferometric synthetic aperture radar (ifsar) data for Alaska. Specifications were created for collecting 3D elevation data, and the data management and delivery systems are being modernized. The National Elevation Dataset (NED) will be completely refreshed with new elevation data products and services. The call for action requires broad support from a large partnership community committed to the achievement of national 3D elevation data coverage. The initiative is being led by the U.S. Geological Survey (USGS) and includes many partners—Federal agencies and State, Tribal, and local governments—who will work together to build on existing programs to complete the national collection of 3D elevation data in 8 years. Private sector firms, under contract to the Government, will continue to collect the data and provide essential technology solutions for the Government to manage and deliver these data and services. The 3DEP governance structure includes (1) an executive forum established in May 2013 to have oversight functions and (2) a multiagency coordinating committee based upon the committee structure already in place under the National Digital Elevation Program (NDEP).

The 3DEP initiative is based on the results of the National Enhanced Elevation Assessment (NEEA) that was funded by NDEP agencies and completed in 2011. The study, led by the USGS, identified more than 600 requirements for enhanced (3D) elevation data to address mission-critical information requirements of 34 Federal agencies, all 50 States, and a sample of private sector companies and Tribal and local governments.

As proposed, the 3DEP effort would begin providing products and services to partners and the public in 2015. The strategy is to leverage funding from partners and to increase contributions from all sources so that the investment rises from the current level of approximately $50 million to $146 million annually. Because 3DEP depends on private sector mapping firms to collect data, jobs will be created as the funding increases. Additional jobs will result when the 3DEP data drive the implementation and development of applications, as documented in the NEEA study. At the full funding level, 3DEP could return more than $690 million annually in new benefits directly to the private sector and indirectly to citizens through improved government program services. When 3DEP data are widely available, further private sector and government innovations will follow for years to come.

Introduction

The 3D Elevation Program (3DEP) initiative began in 2012 with the preparation of standards for the collection of three-dimensional (3D) elevation data and the modernization of data management and delivery systems. For the program to be successful, broad support is essential, and the initiative includes a call for action to accelerate the collection of remotely sensed high-resolution data of two types: (1) high-quality light detection and ranging (lidar) data for the conterminous United States (CONUS), Hawaii, and the U.S. territories and (2) interferometric synthetic aperture radar (ifsar) data for Alaska. Lidar is an essential remote-sensing technology needed to support high-value applications, including flood risk management, agriculture and precision farming, infrastructure and construction management, natural resource management and conservation, and geologic resource assessment and hazard mitigation. Lidar is one of two primary technologies used in the United States to map elevation and other Earth-surface characteristics. Ifsar, while lower in absolute accuracy and resolution, has the ability to penetrate cloud cover and can also be obtained for a lower cost because the sensors can be carried by aircraft flying at higher altitudes and ground speeds than those needed for lidar. For these reasons, ifsar is the preferred technology for Alaska, where remoteness and persistent cloud cover often preclude the use of lidar. The 3DEP goals are to complete one cycle of lidar and ifsar data collection for the Nation and to completely refresh the National Elevation Dataset (NED) with new elevation data products and services.

The lidar and ifsar data to be collected for 3DEP are useful for many business applications that require more robust data than a basic bare-earth digital elevation model (DEM). Lidar data are collected from aircraft by using sensors that detect the reflections of a pulsed laser beam. The reflections are recorded as millions of individual points, collectively called a "point cloud," that represent the 3D positions of objects on the surface of the Earth (fig. 1). The objects can be buildings, vegetation, the ground, or any other feature. The points are usually classified by the type of feature from which they were reflected, allowing various surface models to be created, such as a digital surface model (DSM; a first-return surface) or a DEM (a bare-earth surface). In addition, the intensity of the reflected light is measured and stored as an attribute of the point, allowing a type of image to be created from the lidar data. The lidar point cloud data can be further processed to model the shape and volume of buildings, the size of trees or density of vegetation, land cover categories, line of sight, and many other physical phenomena to support a wide variety of applications.

Ifsar, a type of radar, uses longer wavelength (primarily X-band) radio wave pulses from the sensor. The typical ifsar system produces lower accuracy, less detailed data than lidar, it does not penetrate vegetation as thoroughly as lidar, and it is limited to producing DEMs, DSMs, and radar images. However, ifsar has the advantages of being able to penetrate cloud cover and operate from higher altitudes at higher flight speeds. These advantages allow data to be collected very quickly for very large areas and in less than ideal weather conditions, making ifsar an attractive alternative to lidar for large collections in remote and challenging environments when high precision is not critical.

The U.S. Geological Survey (USGS) was designated by the Office of Management and Budget (in 2002 through OMB Circular A–16) as the lead Federal agency for terrestrial elevation data. The 3DEP initiative is designed to fulfill that leadership responsibility and to ensure that the needs of the Nation for high-quality 3D elevation data are being met. This role cannot be filled by the USGS alone, and the 3DEP initiative is a collaborative answer to this challenge. The initiative includes many partners—Federal agencies and State, Tribal, and local governments—who will work together to build on existing programs to complete the national collection of 3D elevation data in 8 years. Private sector firms, under contract to the Government, are collecting the data and providing essential technology solutions to manage and deliver these data and services. The governance structure includes (1) an executive forum established in May 2013 to have oversight functions and (2) a multiagency coordinating committee based upon the committee structure already in place under the National Digital Elevation Program (NDEP).

The 3DEP initiative is based on the results of the National Enhanced Elevation Assessment (NEEA) that was funded by NDEP agencies and completed in 2011; the report of the study was revised in 2012 (Dewberry, 2012; Snyder and others, 2014). The study, led by the USGS, identified more than 600 requirements for 3D elevation data to address mission-critical information requirements of 34 Federal agencies, all 50 States, and a sample of private sector companies and Tribal and local governments. Many requirements were identified where high-quality 3D elevation products would never be affordable if the data were acquired to solely meet a specific need. For example, the wind power industry requires volumes

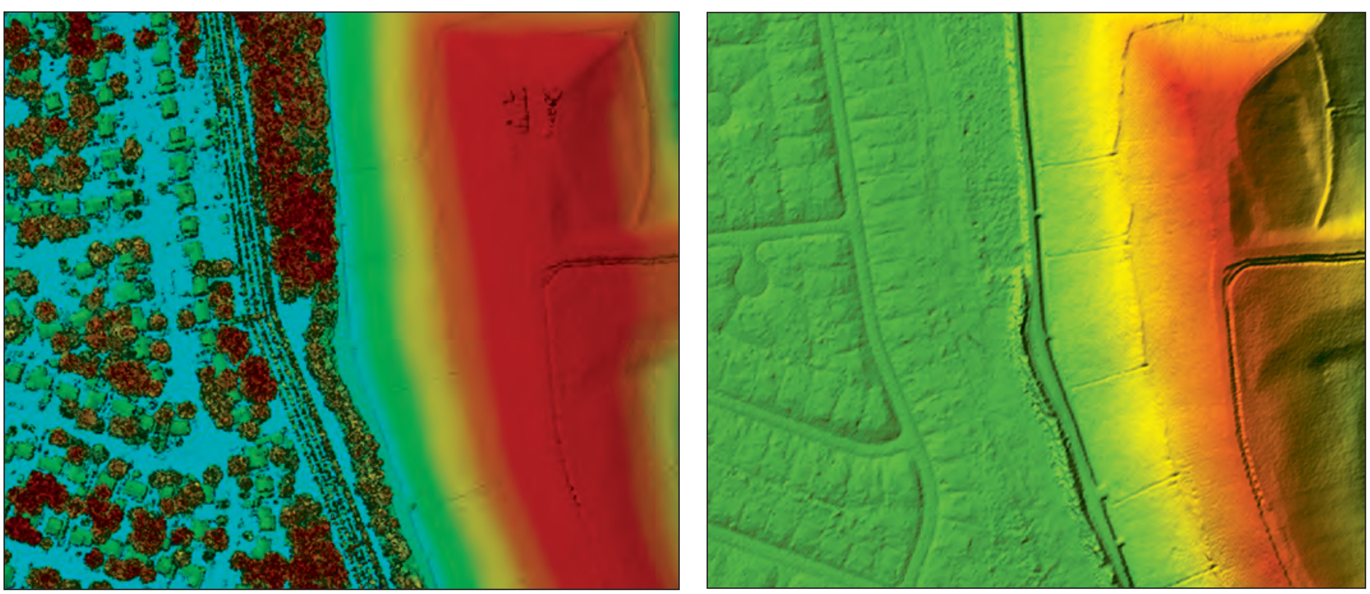


Figure 1. Images from lidar classified point cloud data on the left and digital elevation model (DEM) data on the right depict the same portion of a residential community in Norfolk, Virginia. The trees and homes can be seen in the point cloud lidar image. The DEM image shows the bare earth after trees and structures were removed from the point cloud data. The DEM is color coded by elevation, clearly showing the earthen flood-control structure in orange and red and the lower elevation residential area in green. Images courtesy of Dewberry. Definition: lidar, light detection and ranging.

of very high quality surface data for large areas to plan wind farms and to determine ideal placement of wind turbines. It would be costly for this industry to fund the acquisition of high-quality lidar data solely to support that purpose. Yet, when all of the overlapping needs from multiple users are considered, a national program is more than justified. The NEEA study identified many examples like the wind farm application where a single use could not justify the necessary investment in lidar or ifsar data. In contrast, funding for data collection today comes from government agencies where mission-specific needs, with justifiable lidar investments, are driving data acquisitions. Although the mission-driven data-collection strategy has benefited individual projects and government programs, it will not result in the national dataset needed to achieve the benefits, as documented in the NEEA report.

In a resource-constrained environment, partner agencies cannot rely only on increased funding to advance the goals of 3DEP. Improved program efficiencies and advancements in technology to increase the rate of collection of elevation data will also be necessary. The 3DEP initiative is designed to achieve a 25-percent cost-efficiency gain by collecting data in larger projects. To achieve national coverage in 8 years, however, the overall rate of data collection will need to increase threefold. In order to create the level of participation from cooperating agencies, and to ensure that mission needs can be addressed, the initiative includes the following proposals:

- Increase overall investments through budget and other initiatives in order to provide greater incentives for increased partner engagement.

- Ensure that the mission needs of partner agencies are addressed by soliciting 3-year acquisition priorities and considering those needs in the 3DEP acquisition process.

- Encourage Federal, State, and Tribal government participation through advantageous partnerships that adhere to accepted quality standards while recognizing the need for flexibility among partners.

- Achieve efficiencies and lower costs through acquisition projects for large areas.

- Take advantage of ongoing, improved private industry capabilities for collecting, processing, storing, and managing elevation data.

- Manage 3D elevation data and make them freely available for everyone.

As proposed, the 3DEP effort would begin providing products and services to partners and the public in 2015. The strategy is to leverage funding from partners and to increase contributions from all sources so that the investment rises from the current level of approximately $50 million to $146 million annually. Because 3DEP depends on private sector mapping firms to collect data, jobs will be created as the funding increases. Additional jobs will result when the 3DEP data drive the implementation and development of applications, as documented in the NEEA study (Dewberry, 2012). At the full funding level, 3DEP could return more than $690 million annually in new benefits directly to the private sector and indirectly to citizens through improved government program services (Dewberry, 2012). When 3DEP data are widely available, further private sector and government innovations will follow for years to come.

Background

As the lead Federal agency for terrestrial elevation data, the U.S. Geological Survey has managed the NED and coordinated its activities through the NDEP for more than 15 years. The NED, managed as part of *The National Map* (*http://nationalmap.gov/*), has represented the standard of quality for elevation data in the United States during this time. Today, new elevation data are acquired using lidar and ifsar technologies to replace elevation data that are, on average, more than 30 years old. Through the coordinated efforts of the NDEP, a project-by-project data-acquisition approach has resulted in publicly available data for 26 percent of the conterminous United States, Hawaii, and the U.S. territories and 37 percent of Alaska over the past 13 years (fig. 2).

While the NDEP efficiently coordinates among Federal agencies and other partners, the rate of data collection and the typical project specifications are insufficient to address many data requirements of government, the private sector, and others. Technologies for collecting and managing elevation data have changed significantly. Lidar and ifsar data have made it feasible to collect large quantities of data that map the Earth's surface, including infrastructure and vegetation. These technology changes create an opportunity to address a wider range of needs and a challenge to modernize the way the USGS defines and carries out its mapping activities. The potential to address requirements for natural hazards assessment and mitigation, natural resource conservation, infrastructure development, agricultural production, national security and environmental protection, and other applications requires a fresh perspective. An ambitious 3DEP initiative by the USGS and partner Federal, State, and Tribal governments, working with photogrammetry and geographic information system professionals in private sector mapping firms, is responding to these needs. The initiative represents a significant opportunity to support the Nation's resource managers, scientists, and environmental professionals. It would improve the efficiency and effectiveness of government programs and advance technologies for key industry applications such as precision farming and alternative energy development. The need for 3DEP is well supported by a yearlong National Enhanced Elevation Assessment (NEEA) completed by the USGS and partner agencies (Dewberry, 2012) to assess the national requirements for elevation data and the benefits that would be realized from improved 3D elevation data.

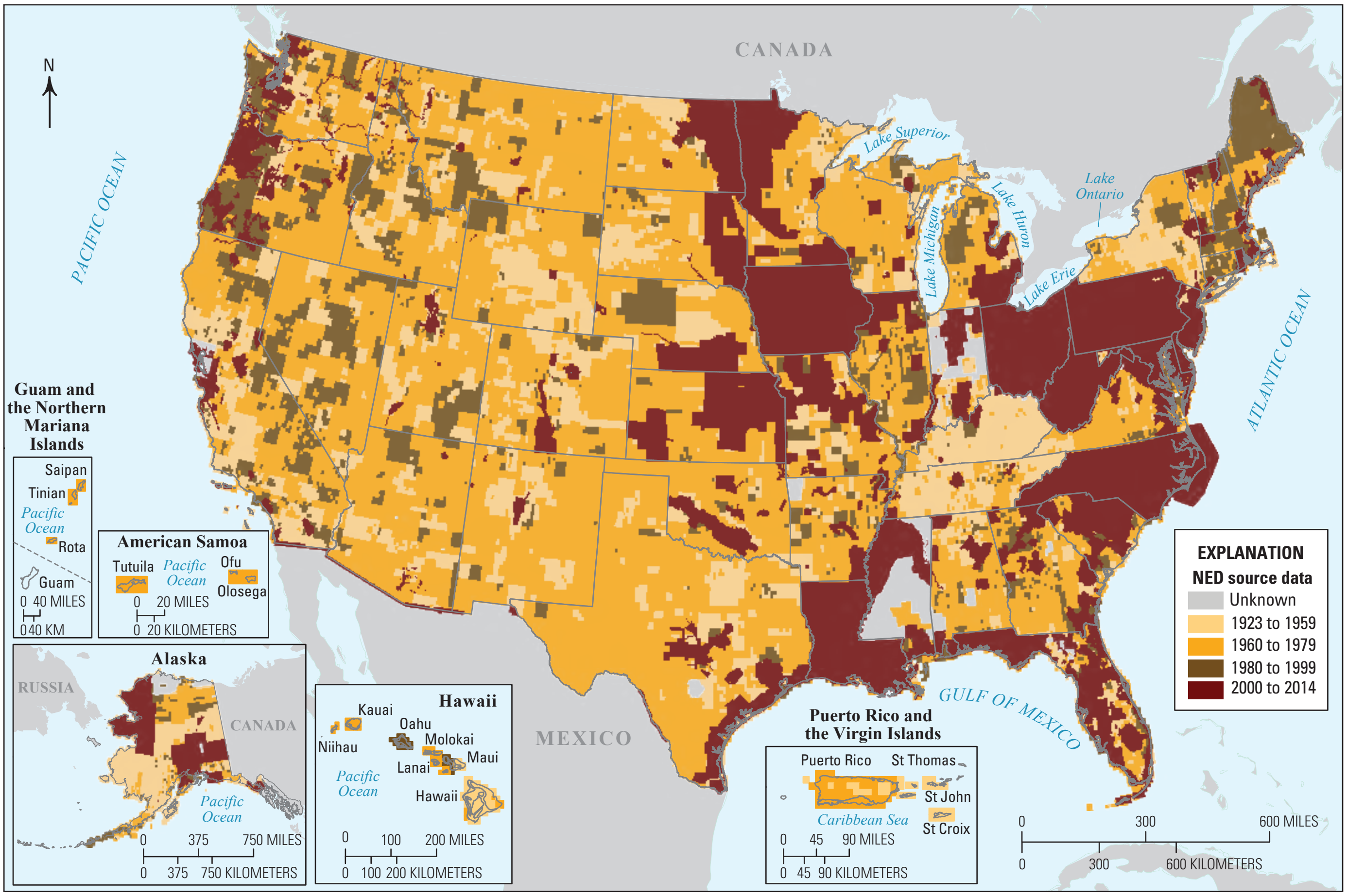


Figure 2. Map of the United States showing the status of the National Elevation Dataset (NED) as of May 2014. The NED is maintained by the U.S. Geological Survey (USGS) at multiple resolutions for the United States. Generally, digital elevation models (DEMs) are derived from light detection and ranging (lidar) data acquired after 2000, which are available for 26 percent of the conterminous United States, Hawaii, and the U.S. territories. Alaska has DEMs derived from interferometric synthetic aperture radar (ifsar) data for about 37 percent of the State. The remaining areas have coarser resolution DEMs created prior to 2000 from contours on scanned USGS topographic maps.

USGS Commitment to Manage National Elevation Data Assets

The OMB Circular A–16, "Coordination of Geographic Information and Related Spatial Data Activities" (Office of Management and Budget, 2002), provides for improvements in the coordination and use of spatial data and describes effective and economical use and management of spatial data assets in the digital environment for the benefit of the Federal Government and the Nation. Circular A–16 designates the U.S. Geological Survey (part of the Department of the Interior [DOI]), as the lead agency for the coordination and management of the Nation's terrestrial elevation data and designates the National Oceanic and Atmospheric Administration (NOAA; part of the Department of Commerce) as the lead agency for bathymetric data. The 3DEP initiative continues and improves upon the USGS commitment to coordinate the collection of terrestrial elevation data, to assess data contributed by partners, and to manage these authoritative national elevation data assets.

The supplemental guidance issued in 2010 for OMB Circular A–16 (Office of Management and Budget, 2010) was used throughout the planning and program development process. Though terminology may vary, the steps, intermediate products, and expected outcomes of 3DEP are intended to fully implement and be compliant with the guidance as it relates to the management of National Geospatial Data Assets (NGDAs). The plan described in this report covers one complete geospatial data lifecycle as outlined in the guidance (fig. 3). However, it is neither the beginning, nor is it the end. The USGS has a long history of managing elevation data, and 3DEP is a natural extension to address a wide range of new and emerging needs. The 3DEP initiative embodies the model of portfolio management and cooperative programs that will improve efficiency across all levels of government. The USGS, in its role to manage the 3DEP data assets, plans to facilitate an NDEP review of existing and new datasets

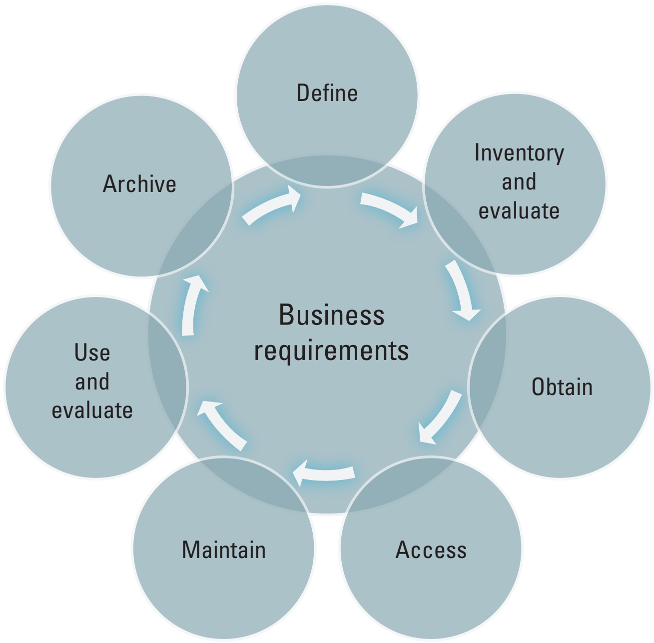


Figure 3. Diagram showing seven stages in the geospatial data lifecycle. The stages are based on business needs and are summarized as follows: **Define**—Characterize data needs; **Inventory and evaluate**—Create and publish lists of data assets and gaps; **Obtain**—Identify ways to acquire data: **Access**—Make data available to users; **Maintain**—Keep data available; **Use and evaluate**—Assess and validate data and plan for potential enhancements to data; and **Archive**—Retain data and plan for long-term storage. Figure derived from the supplemental guidance issued in 2010 for OMB Circular A–16 (Office of Management and Budget, 2010, fig. 3).

to determine which managed datasets should be designated as NGDAs under OMB Circular A–16. In fulfillment of its responsibilities to manage NGDAs and to track program implementation progress, the USGS plans to complete an annual report on the state of the elevation data.

USGS managers of the 3DEP initiative intend to fully coordinate the management of terrestrial elevation data with the programs responsible for bathymetric data at NOAA. The partner agencies are working to bring these two historically separate data activities together. The work is being accomplished, in part, under a cooperative effort to build a Coastal National Elevation Database (CoNED) and through coordination with the Interagency Working Group on Ocean and Coastal Mapping (IWG–OCM). The coordination is not as simple as building integrated datasets, as it requires understanding respective missions and creating datasets that address the broader needs of Federal, State, Tribal, and local governments and the private sector. There is an ongoing dialogue between NOAA and the USGS. Today, both agencies participate in elevation data coordination activities, share a system to inventory available elevation data, and are working collaboratively to plan for a more integrated data future.

Assessment of Requirements

The NEEA, completed in December 2011 (Dewberry, 2012), was conducted to (1) document national-level requirements for 3D elevation data, (2) estimate the benefits and costs of meeting those requirements, and (3) evaluate multiple national-level program-implementation scenarios. The assessment was sponsored and funded by the NDEP's member agencies. The study participants included 34 Federal agencies, agencies from all 50 States, selected local government and Tribal offices, and private and not-for-profit organizations. In all, 602 mission-critical activities were summarized by major business uses that need higher quality data and products from lidar and ifsar source data than are currently available. The results of the assessment indicate that 3D elevation data have the potential to generate $13 billion in new benefits annually.

All organizations identified key functional activities, described in their own words, with mission-critical requirements for 3D elevation data, along with their elevation data requirements by quality level (table 1), update frequency, and geographic area. Each functional activity was linked to the business use that was most similar to the described activity. These data were collected by an online questionnaire, interviews, and workshops; they were finalized during a validation process that resulted in the formal documentation of each organization's requirements and anticipated benefits. All of these data were entered into a master geodatabase. The full NEEA report (Dewberry, 2012) includes detailed documentation for 104 functional activities from 34 Federal agencies, 329 functional activities from 50 States and U.S. territories, and 144 functional activities from local and Tribal governments. Twelve private companies and one not-for-profit organization documented 25 more functional activities.

All elevation data requirements were aggregated and analyzed, and benefits for each functional activity and business use were determined. Each functional activity was summarized for its mission-critical elevation data requirements by quality level (QL) and update frequency and by its conservative and potential benefits in dollars, annually. The conservative benefits total $1.2 billion per year and the potential benefits total $13.0 billion per year (table 2). In subsequent analysis and development of implementation scenarios, partial benefits may still be realized if users receive poorer QL data or less frequent updates than optimally required for each functional activity. State requirements and benefits varied for similar activities. For example, one State reported significantly higher benefits for coastal flood risk management than did other coastal States. Some States were unable to determine dollar benefits for flood risk management even though they reported there were major benefits. Examples of six business uses having high conservative or potential benefits are shown in figure 4.

Conservative benefits in table 2 are believed to be significantly underestimated for several reasons:

- The assessment did not identify and capture all applications for elevation data.
- Approximately half of the organizations were unable to estimate expected dollar benefits, even though most of these same organizations reported that they expected moderate or major benefits.
- Environmental or ecosystem service benefits usually fell into the category of unquantifiable.
- Some benefits were provided as a range of dollars, and, for such responses, the number representing the low end of the range was used.
- Benefits used in the benefit and cost analysis do not include county, regional, city, and Tribal governments because the sample pools for these organizations were too small to support national projections.

The potential benefits are also believed to be underestimated and could be one or more orders of magnitude greater if the study had included the expected benefits of every county, regional, city, and Tribal government and other industries nationwide.

Table 1. Data quality levels and related accuracies for the 3D Elevation Program (3DEP) initiative.

[These elevation data collection parameters for the 3DEP initiative approximate those used in the National Enhanced Elevation Assessment (NEEA) study (Dewberry, 2012), which categorized elevation source data into five quality levels (QLs). They have been adjusted slightly to conform to the draft 2014 “ASPRS Positional Accuracy Standards for Digital Geospatial Data” (American Society for Photogrammetry and Remote Sensing, 2014). QL3 approximates the base-level specification for lidar data collected by the U.S. Geological Survey (USGS) through fiscal year 2013 (Heidemann, 2012). The specification is under revision to reflect QL2 as the base level, in accordance with the 3DEP initiative recommendation. Note that the QL nomenclature has evolved from its first usage in the NEEA study and its subsequent use in the USGS acquisition specification. Definition: n/a, not applicable]

Quality level	Data source[1]	Vertical error ($RMSE_Z$)[2] (centimeters)	Nominal pulse spacing (NPS)[3] (meters)	Nominal pulse density (NPD)[4] (points per square meter)	Digital elevation model (DEM) cell size (meters)
QL1	Lidar	10	0.35	8	0.5
QL2	Lidar	10	0.7	2	1
QL3	Lidar	20	1.4	0.5	[5]2
QL4	Aerial imagery	139	n/a	n/a	5
QL5	Ifsar	185	n/a	n/a	5

[1]Data sources: ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging.

[2]$RMSE_Z$ is the root mean square error in the *z* (elevation) dimension.

[3]NPS is the typical or average lateral distance between irregularly spaced first-return points in a lidar dataset, most simply calculated and expressed as the square root of the average area per elevation point. It is the square root of the reciprocal of the NPD.

[4]NPD estimates the number of first-return lidar points per square meter. It is the square of the reciprocal of the NPS.

[5]Although many historical DEMs created from QL3 data have had a resolution (cell size) of 3 meters to match the 1/9 arc-second National Elevation Dataset (NED), the QL3 data will support the production of a 2-meter DEM.

Table 2. Annual benefits from the use of 3D elevation data as identified by participants in the National Enhanced Elevation Assessment (NEEA) for the functional activities aggregated into 27 business uses.

[For benefits that were identified as a range, the conservative value represents the lower end and the potential value represents the upper end of the range. With the exception of the potential benefit of $7 billion associated with land navigation and safety, all of the dollar benefits represent immediate needs. The land navigation benefit is realized from vehicle fuel reductions that are expected to result from intelligent vehicle navigation systems. In addition to the identified dollar benefits, all of the business uses were identified by NEEA respondents as having mission-critical activities requiring 3D elevation data whether or not they were able to quantify the benefits. The NEEA report identifies those benefits as “major or moderate but not quantified” (Dewberry, 2012, p. 558–670). Table modified from Snyder and others (2014, p. 7, table 2) and Dewberry (2012, p. 5, table 1.3). Definitions: 3D, three dimensional; dollars, constant 2012 dollars; K–12, kindergarten through twelfth grade]

Rank[1]	Business use	Annual benefits, in millions of dollars	
		Conservative	Potential
1	Flood risk management	294.7	501.6
2	Infrastructure and construction management	206.2	942.0
3	Natural resources conservation	159.2	335.2
4	Agriculture and precision farming	122.3	2,011.3
5	Water supply and quality	85.3	156.4
6	Wildfire management, planning, and response	75.7	159.0
7	Geologic resource assessment and hazard mitigation	51.8	1,066.8
8	Forest resources management	43.9	61.7
9	River and stream resource management	38.4	86.6
10	Aviation navigation and safety	35.0	56.0
11	Coastal zone management	23.8	41.7
12	Renewable energy resources	10.1	100.1
13	Oil and gas resources	10.0	100.0
14	Homeland security, law enforcement, disaster response	10.0	126.5
15	Sea level rise and subsidence	5.8	21.7
16	Urban and regional planning	4.2	68.6
17	Resource mining	1.7	4.9
18	Wildlife and habitat management	1.5	4.0
19	Education K–12 and beyond	0.3	2.3
20	Land navigation and safety	0.2	7,124.9
21	Telecommunications	0.2	1.9
22	Recreation	0.1	0.1
23	Cultural resources preservation and management	0.0	7.0
24	Health and human services	0.0	1.0
25	Marine navigation and safety	0.0	0.0
26	Real estate, banking, mortgage, insurance	0.0	0.0
27	Rangeland management	0.0	0.0
	Total for all business uses	**1,180.4**	**12,979.3**

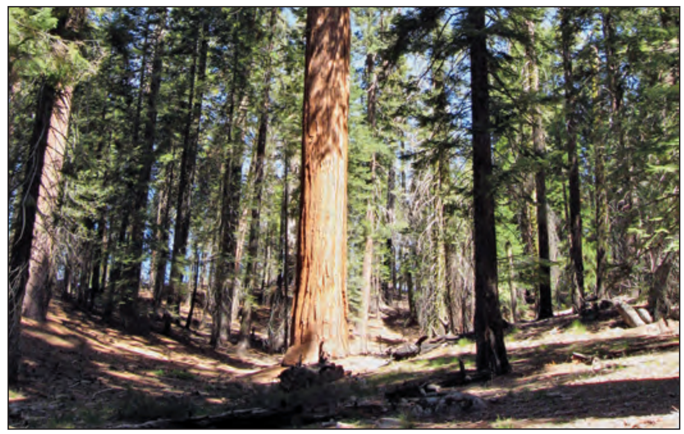
[1]Rank is based on the conservative estimates of annual benefits to be derived from the use of 3D elevation data.

***A.* Agriculture and precision farming**

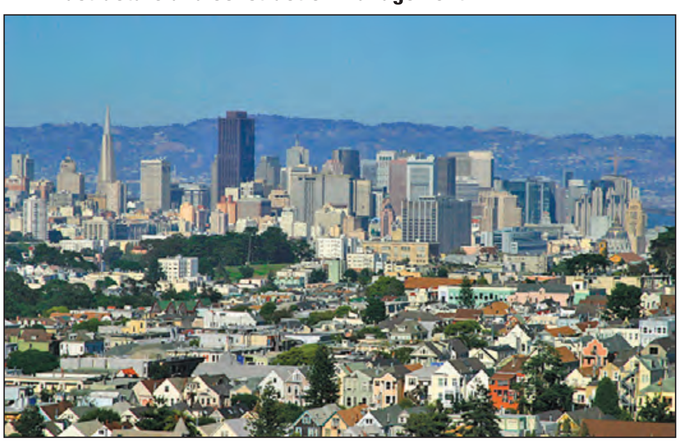
***B.* Land navigation and safety**

***C.* Geologic resource assessment and hazard mitigation**

***D.* Natural resources conservation**



***E.* Infrastructure and construction management**



***F.* Flood risk management**

Figure 4. Photographs showing examples of 6 of the 27 business uses for 3D elevation data that were chosen in the National Enhanced Elevation Assessment (Dewberry, 2012) to organize the 602 mission-critical activities identified in the study. The uses illustrated are (*A*) agriculture and precision farming, (*B*) land navigation and safety, (*C*) geologic resource assessment and hazard mitigation, (*D*) natural resources conservation, (*E*) infrastructure and construction management, and (*F*) flood risk management. Sources: figure 4*A* is a Natural Resources Conservation Service photograph of crops in California; figure 4*B* is a photograph by Thomsonmg2000 of U.S. Route 25 in South Carolina (from *http://commons.wikimedia.org/wiki/File:U.S._Route_25_South_Carolina.JPG#file*); figure 4*C* is a U.S. Geological Survey photograph showing a road damaged by the January 17, 1994, Northridge, California, earthquake; figure 4*D* is a photograph by Caryl Wipperfurth (USGS) showing giant sequoias in Sequoia National Park, California; figure 4*E* is a photograph by Aaron Logan showing San Francisco (from *http://commons.wikimedia.org/wiki/File:Lightmatter_sanfrancisco.jpg*); figure 4*F* is a photograph by M. Huard (USGS) of the International Bridge in Fort Kent, Maine, April 30, 2008, during a record-setting flood for that site.

Benefit and Cost Analysis and Recommended Data-Acquisition Scenario

The geographic extents of mission-critical data needs were mapped for each functional activity, and a geodatabase was created to support the analysis. The data requirements were aggregated into cells measuring one degree of latitude by one degree of longitude, and the probable benefits and costs of a national program were computed for every cell for each of 25 program-implementation options. The 25 options were based on various combinations of data QLs and refresh cycles. Where data were required for a portion of a cell at a particular QL, the benefits were prorated such that benefits would not be overstated for any cell. The estimated costs for each option included those for data collection and life-cycle management. The benefit analyses used the conservative benefit estimates. In addition, environmental and ecosystem services were generally not quantified and, therefore, did not contribute to the benefit analysis.

On the basis of the 25 options, a set of national program implementation scenarios was developed that would optimize every cell for QL and replacement cycle (or some combination of the two) for a Federal-only program and national strategies that considered all needs. Other scenarios were developed that would hold QLs and replacement cycles constant. The final analysis yielded 10 leading scenarios (fig. 5). Each scenario would implement a national data-collection strategy to achieve cost efficiencies and meet the requirements of multiple organizations. While it was possible to lower costs slightly, none of the optimized scenarios offered the benefits of national consistency. All of the scenarios assumed ifsar data coverage in Alaska, where cloud cover and remoteness preclude consideration of lidar data acquisition for much of the State. A detailed overview of each of the leading scenarios can be found in the full NEEA report (Dewberry, 2012).

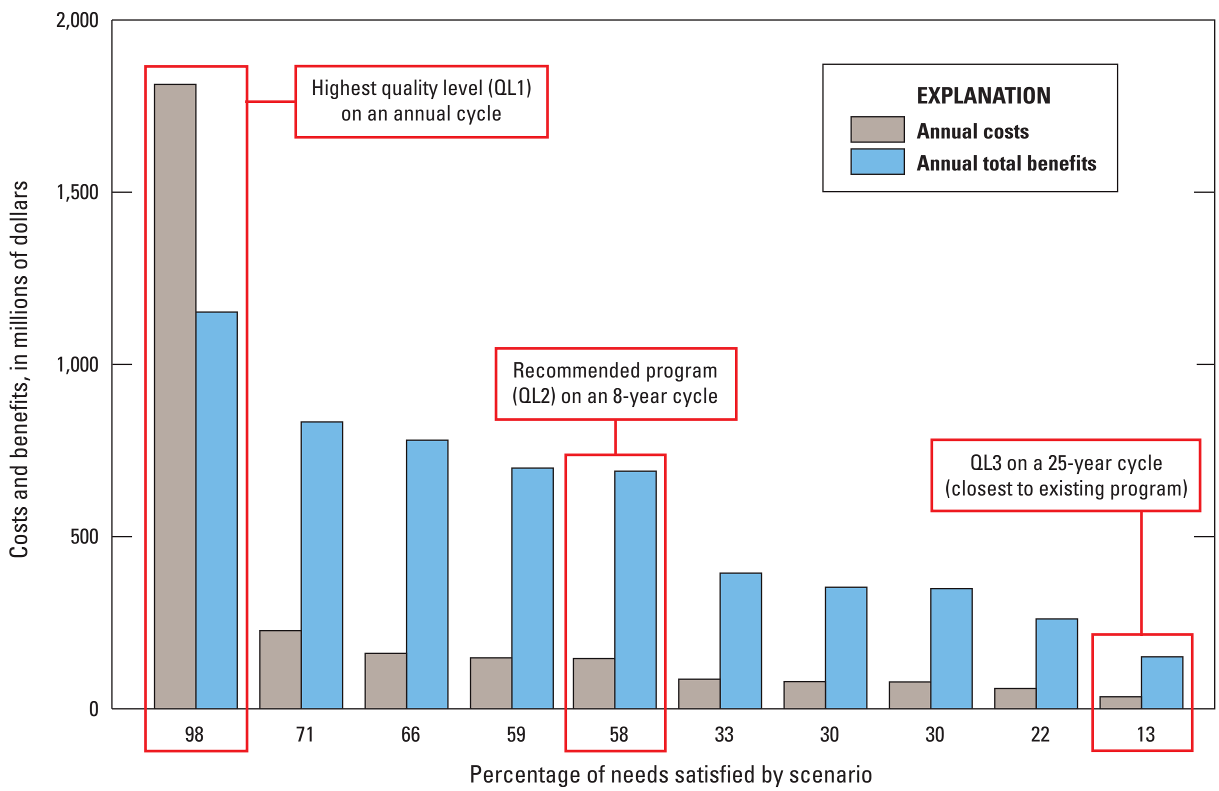


Figure 5. Graph showing annual costs and benefits of 10 program scenarios that were analyzed for different investment levels and resulting benefits (needs met) from acquiring elevation data at different quality levels (QLs) and acquisition cycles. Costs and benefits are in constant 2012 dollars. On the left side of the graph, QL1 data acquired annually are represented. For this scenario, the costs significantly exceed the benefits. To the far right, a QL3 program for data collected over a 25-year period has a favorable benefit/cost ratio with corresponding low benefits. The recommended program would achieve about 58 percent of the benefits, as shown in the middle of the graph. The depicted costs and benefits are average annual costs and benefits for a fully operational program. Detailed descriptions and the full results of the scenarios considered can be found in the National Enhanced Elevation Assessment report (Dewberry, 2012).

A midrange scenario offers a high benefit/cost ratio of 4.7/1, uniform QL2 data, and an 8-year acquisition cycle. The cell-by-cell benefit/cost ratio for this program scenario is shown in figure 6. For Alaska, ifsar QL5 data would be collected over 5 years as part of the Alaska mapping initiative. Nearly all cells have a positive benefit/cost ratio in this scenario. The exceptions include arid regions of the western United States that are predominantly in Federal ownership. If this scenario is viewed from the perspective of return on investment (fig. 7), a positive return on investment is realized

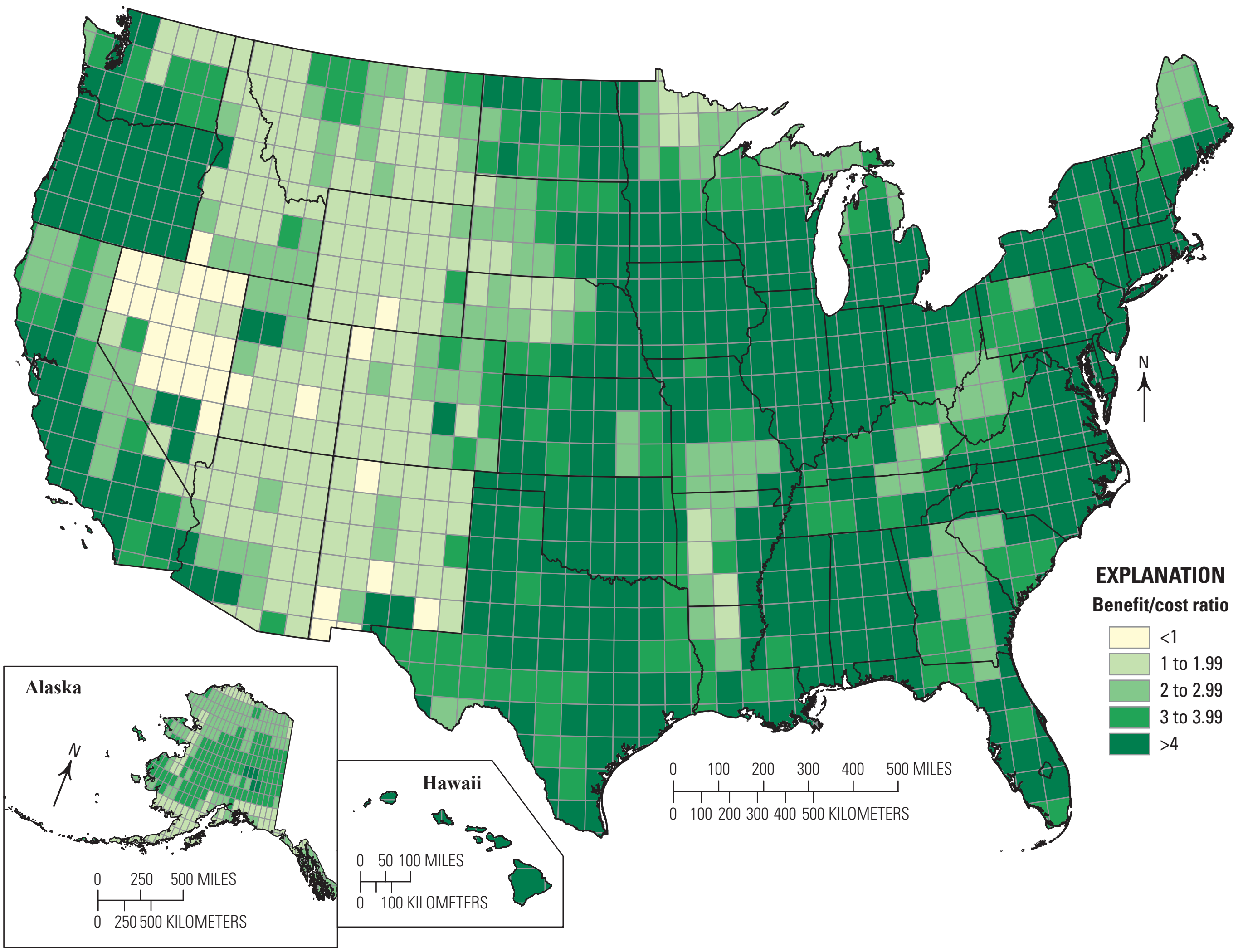


Figure 6. Map of the United States showing variations in the benefit/cost ratio for the recommended program that would acquire uniform quality level 2 (QL2) elevation data for the conterminous United States and Hawaii and QL5 data for Alaska. The benefits are based on total dollar benefits from all sources. Values are in constant 2012 dollars. The darker shades represent the higher benefits. Map depicts U.S. Geological Survey analysis of data in Dewberry (2012).

in less than 14 years in all cells. There are many business uses in the U.S. arid regions where NEEA study participants were unable to assign dollar benefits. If quantified, these benefits would increase the benefit/cost ratios in those cells. Many of the NEEA study participants indicated that QL consistency was important for their applications. Analysis of the return-on-investment periods indicates that extending the acquisition cycle is better than collecting lower quality data in these areas. The added benefits of national consistency led to the recommendation of the QL2, 8-year-cycle scenario.

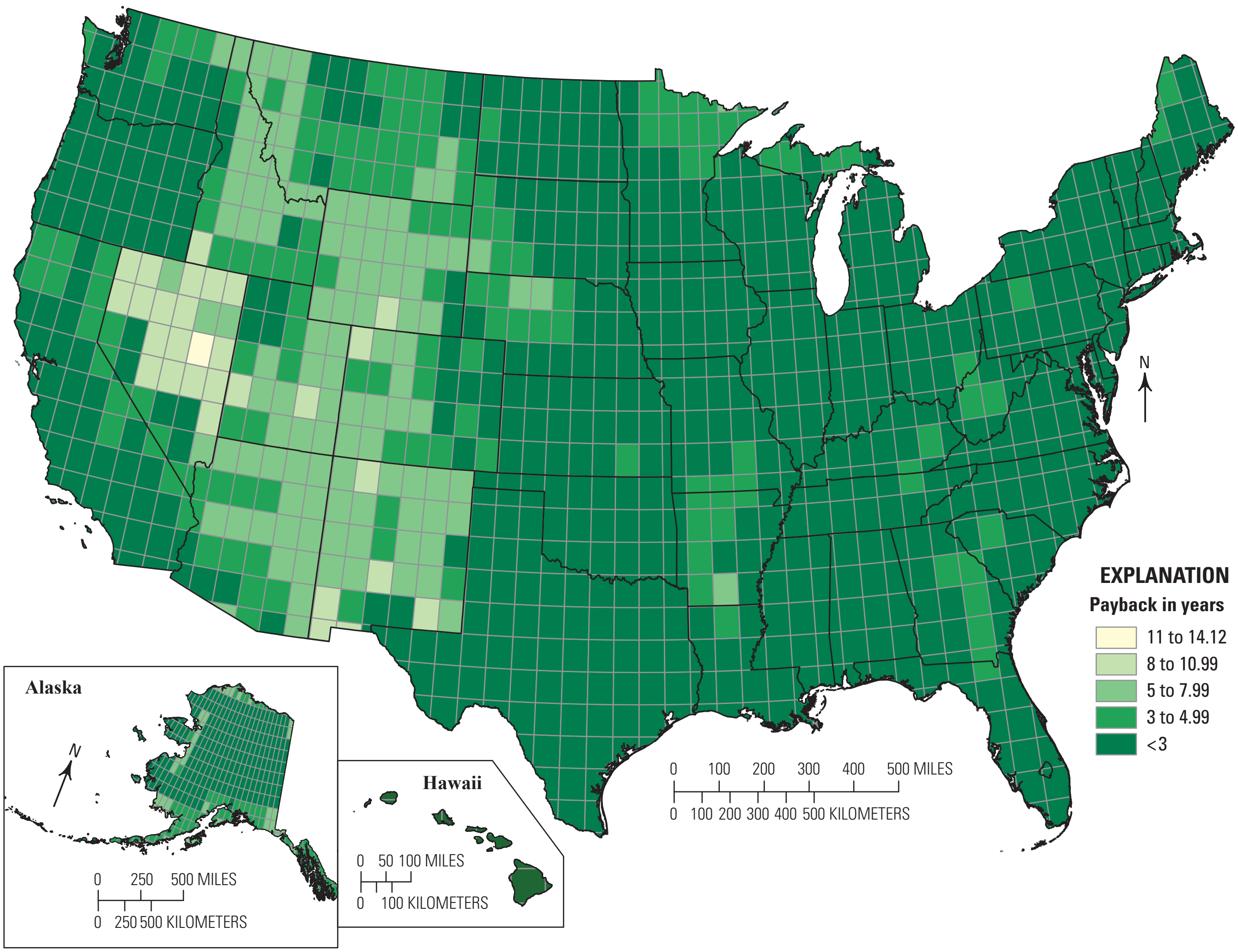


Figure 7. Map of the United States showing the return-on-investment (payback) periods for the recommended program that would collect uniform quality level 2 (QL2) elevation data for the conterminous United States and Hawaii and QL5 data for Alaska. The return-on-investment period is less than 3 years for most of the country. The lowest return on investment is in some of the arid western States, where a 14-year return on investment is possible. The darker shades represent the shorter returns on investment. Map depicts U.S. Geological Survey analysis of data in Dewberry (2012).

3D Elevation Program (3DEP) Initiative

Following the analysis and vetting of the NEEA study, the QL2, 8-year-cycle scenario for collecting elevation data was recommended by the NDEP committee and its 12 Federal member agencies. The 3D Elevation Program was endorsed by or received letters of budget support from the American Society for Photogrammetry and Remote Sensing (ASPRS), the Association of American State Geologists (AASG), the Association of State Floodplain Managers (ASFPM), the Coalition of Geospatial Organizations (COGO), the Management Association for Private Photogrammetric Surveyors (MAPPS), the National Geospatial Advisory Committee (NGAC), the National Society of Professional Surveyors (NSPS), and the National States Geographic Information Council (NSGIC).

The 3DEP initiative was created to respond to the documented need for high-quality topographic data and other information derived from lidar and ifsar data for the Nation's natural and constructed features. The primary goal of the program is to systematically acquire 3D elevation data for the United States and the territories. The private sector, under government contract, will provide data-collection and related services to respond to these needs for lidar and ifsar data. The resulting products and services will be freely accessible to all levels of government and the public.

According to the benefits identified in the NEEA study, the Federal agencies poised to realize the highest benefits to their mission from 3D elevation data include the Natural Resources Conservation Service, the U.S. Army Corps of Engineers, the Defense Installation Spatial Data Infrastructure, the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, the Federal Emergency Management Agency, the Environmental Protection Agency, the U.S. Forest Service, the Federal Aviation Administration, and the National Geospatial-Intelligence Agency. States and other partners will benefit from and be able to fully participate in 3DEP. The 3DEP initiative is a cooperatively funded national elevation initiative led by the USGS. The initiative, designed to meet the mission-critical data needs of 3DEP partners and other users, will continue to function as an activity under *The National Map.* A two-tiered governance model consisting of an executive forum and a coordinating committee will solidify 3DEP partner agency roles and data-acquisition strategies, program expectations, and constraints. The NDEP committee or a successor committee will serve as the multiagency coordinating committee. The target achievement would be fully realized in 8 years (2022) by national coverage of QL2 or better lidar data for 49 States and in territories and by QL5 or better ifsar data for Alaska. Derived products would be available to address high-priority needs, and customers would be able to access and use the original data to create their own value-added products and services.

A steady-state operational activity is planned for 2015 with an initial set of data and new products and services. Existing program activities that will become participants of the 3DEP cooperative initiative include the NDEP committee, the National Elevation Dataset (NED), the Coastal National Elevation Database (CoNED), related research activities, and potentially other 3D elevation data and services. The lidar point cloud data are available through the EarthExplorer data portal of the USGS, and under the 3DEP initiative, lidar, ifsar, and derived elevation products are being made available through *The National Map* data portal. Some programmatic activities are being consolidated to improve overall program efficiencies. Partner Federal agencies, States, and Tribal organizations will contribute to a new planning process to identify their 3-year acquisition priorities and participate in cooperative data-acquisition projects.

The 3DEP initiative includes a program of data collection, data management, and delivery of products and services that encompasses one complete geospatial data lifecycle as described by the OMB A–16 Supplemental Guidance (Office of Management and Budget, 2010). The definition of the first lifecycle should not be interpreted to mean that 3DEP will end after 2022. The plan described in this report intentionally addresses a defined period of time and an accomplishment that can be realized. USGS managers expect that technology will change and that data sensors will become more widely used and may include space platforms. These changes will likely drive costs lower in the future. Eight years from now, 3DEP will look quite different, and it will be time again to assess and evaluate where this important national program needs to go. It is also expected that billions of dollars in benefits to the Nation will have been realized and that ongoing and new needs will shape the future of the next-generation 3DEP.

Project Schedule and Milestones

The project milestones (table 3) represent major and time-sensitive accomplishments leading to the successful implementation of the 3DEP initiative. The schedule is based on assumptions of funding success as outlined in the "Growth" section of this report and additional assumptions of a small but well-defined offering of products and services as described in the "Source Data, Products, and Services" section. While every attempt has been made to accurately represent the current status and direction of 3DEP, the designers expect that the product suite, data-acquisition plans, and operational capabilities will evolve over time and the budget will likely be different from what is projected in this report. Current information about 3DEP will continue to be available on *The National Map* Web site for 3DEP at *http://nationalmap.gov/3DEP/*.

Leadership, Outreach, and Growth

The program of operations for 3DEP will be executed—initially as a series of implementation projects—to transition from the current NED activities to an operational state where lidar, ifsar, and various elevation products are created, managed, and made available to a broad customer base. The program will be supported by an executive forum composed of

Table 3. Implementation milestones for the 3D Elevation Program (3DEP) initiative.

[Detailed explanations for the identified milestones can be found in the respective sections within this report. Definitions: ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging; NED, National Elevation Dataset]

3DEP implementation milestones	Planned completion date
Establish the 3DEP executive forum	May 2013—Complete
Implement 3DEP coordination functions	Early 2015
Products and services—Identify initial offering of planned products and services	October 2013—Complete
Data delivery—Release the NED operations modernization product	April 2014—Complete
Data delivery—Release the lidar and ifsar operations modernization product	October 2014
Data delivery—Release the initial 3DEP products and services	Early 2015
Data sources—Define acquisition specifications for quality level 2 base-level data	September 2014
Data acquisition—Call for 3-year Federal acquisition priorities (updated annually)	August 2014—Complete
Data acquisition—Obtain approval for the new geospatial products and services contracts	November 2014

senior executives from cooperating agencies and by the NDEP committee to facilitate multiagency participation at the senior and operational levels.

Outreach will be a primary aspect of the program, which is highly dependent on a broad base of support and participation from Federal agencies and State and Tribal governments. Initially, outreach has been and will continue to be directed toward building support and a funding base to move the program forward. Equally important is the need to reach out to a growing user base to ensure that the program is responsive to the needs of government to provide the services that will allow the partner organizations to realize the potential benefits that they have identified.

Funding for 3DEP will continue to rely heavily on partnership contributions. Overall, national investments in the collection and lifecycle management of source data need to increase about threefold to about $146 million per year. (The average annual cost from 2010 through 2013 of acquiring all publicly available lidar data [and ifsar data for Alaska] was about $50 million, as estimated on the basis of acquisition costs by quality level [Dewberry, 2012] and reported data collections in the United States Interagency Elevation Inventory [USIEI].) A key component of the strategy is to increase funding to a level that allows the program partners to implement a directed national acquisition strategy without compromising the mission needs of individual partners.

Leadership

The 3DEP executive forum is composed of senior officials from Federal agencies and is chaired by the USGS Associate Director for Core Science Systems. The executive forum will formulate new policies or review and approve policies and priorities as may be recommended by the coordinating committee. The executive forum members will develop and champion funding initiatives to advance the 3DEP initiative. The creation of this forum fills a void of executive oversight and accountability for coordination of resources under a single national elevation program. A goal of 3DEP is to include representatives from State and other organizations in the executive forum or to enable such representatives to have a formal method for providing input as may be allowed by the Federal Advisory Committee Act (FACA).

The coordinating committee will be composed of the partner agencies and other organizations as approved by the executive forum. The implementation of 3DEP as a national program will be different from today's NDEP process that primarily emphasizes information sharing about agency acquisition plans. It will instead focus on developing a joint 3-year strategy to meet the needs of the participating agencies. The initial implementation step will be to incorporate Federal agency 3-year acquisition priorities into the annual acquisition planning. Subsequent years will see the development of and refinements of a 3-year strategy. Thus, the primary responsibilities of the coordinating committee will be to provide input to the data-acquisition plan and to prioritize projects to collect 3D elevation data. The committee will manage the long-term data-collection priorities and will provide critical input on 3DEP products and services needed by the members' respective organizations. In addition, the coordinating committee will provide technical guidance as it relates to the collection of source data and provisioning of products and services.

A committee of the Interagency Working Group on Ocean and Coastal Mapping (IWG–OCM) is developing a National Coastal Mapping Strategy (NCMS) that includes topographic and bathymetric lidar coordination and data collection for the coastal zone. The coordination activities of the IWG–OCM and 3DEP overlap in the coastal zone. It is proposed that there be joint planning activities and that coordination issues be resolved during the early stages of the 3DEP implementation. The 3DEP executive forum, the 3DEP coordinating committee, and the IWG–OCM provide the executive leadership, portfolio management and coordination, and shared terrestrial elevation and bathymetry theme leadership roles as required under OMB Circular A–16.

Outreach

The communications plan for 3DEP will set a schedule and milestones for communicating across 3DEP audiences (table 4) about the initiation of the program. The plan deliverables include a timeline, a definition of communication roles, and a list of materials needed for a successful release of 3DEP products and services in 2015.

Defining the branding relationship of 3DEP to other components of *The National Map* and the positioning of products and services will be important aspects of 3DEP outreach and general communications. The branding process will define how 3DEP nests within *The National Map* and relates to other 3DEP community and USGS organizational components. Deliverables will include updates to and expansion of the 3DEP style guide. A series of outreach products will be developed to include program, State, and industry fact sheets. The 3DEP Web site will be maintained and kept current.

Growth

The 3DEP initiative is predicated on the assumption of moderate growth for fiscal year 2014 (FY14) and accelerated growth in subsequent years. Investments in lidar and ifsar data collection over the past 4 years have been in the range of $50 million annually when all public domain government sources are considered. USGS investments are a small portion of the total investment. For the proposed operational program

Table 4. Target audiences for outreach and communications for the 3D Elevation Program (3DEP).

[The communications and outreach strategy for 3DEP includes a wide range of partners and other constituents. Outreach is needed to gain community support and to successfully implement the partnership approach for data acquisition. Definitions: 3D, three dimensional; DOI, U.S. Department of the Interior; OMB, Office of Management and Budget; USGS, U.S. Geological Survey]

Audience	Description	Key audience groups
Federal executives	Decisionmakers and overseers of Federal programs and budgets	3DEP executive forum Federal budget planning process (DOI, OMB, other Federal departments) Office of Science and Technology Policy (OSTP)
Partners	Organizations that partner with the USGS to collect data or provide programmatic advice	Federal, State, local, Tribal, and other partners 3DEP coordinating committee Federal Geographic Data Committee (FGDC) and National Geospatial Advisory Committee (NGAC)
Geospatial user community	Organizations that use 3D elevation data to meet mission objectives	Federal, State, local, Tribal, and other users Esri International and Federal User Conferences Outreach events related to business uses with significant benefits from a national 3D elevation program
Potential new industry users	Industries that would benefit from 3D elevation data and that are outside of the current data user community	Vehicle navigation industry Precision farming industry Forest products industry Renewable energy industry Others to be determined
Professional community	Groups that provide a venue for communicating opportunities and issues associated with a given professional field	American Society for Photogrammetry and Remote Sensing (ASPRS) Association of American State Geologists (AASG) Association of State Floodplain Managers (ASFPM) Coalition of Geospatial Organizations (COGO) Management Association for Private Photogrammetric Surveyors (MAPPS) National Society of Professional Surveyors (NSPS) National States Geographic Information Council (NSGIC) Others
Legislative	Congressional members and staff and organizations that determine or influence Federal and State budgets	USGS, DOI informational visits to Congress members and staff Outreach by 3DEP stakeholders
Media and public	Media and those who could raise 3DEP awareness across user communities and the general public	Trade publications (for example, Directions Magazine, Point of Beginning, ArcNews) Newspapers, television 3DEP Web site and fact sheets

to be fully realized will require a $1,168 million investment (Dewberry, 2012) between 2012 and 2022. The funding graph in figure 8 is one concept of a funding model and is not intended to allocate cost shares to any particular organization or to individual government sectors. The actual funding model and sources of funds are expected to evolve and change as the program matures.

Numerous assumptions went into this investment model, and they could change over time. The key assumptions are as follows:

- QL2 lidar data will be collected over the conterminous United States during 8 years once the program is fully operational.
- Higher quality lidar may be acquired through partner buy-up options. These costs are not included in the basic program funding assumptions.
- QL5 ifsar data will be collected over Alaska.
- Larger data acquisition projects will result in a 25-percent cost savings when compared to 2013 acquisition costs. Should new technologies become commercially available, data-collection costs may be further reduced due to efficiency gains in sensor technologies.
- Approximately 9 percent of total program costs will be required for lifecycle management activities to include a limited research budget to address operational research needs. These are preliminary estimates based on infrastructure sizing and management projections from the NEEA study.
- All costs and budget estimates are based on constant 2012 dollars.
- There will continue to be slow but continuous growth in lidar and ifsar investments by partner institutions. The investment growth for partners will lag USGS investments initially and catch up in out years as partners anticipate matching funds and plan for future acquisitions.
- A consortium of Federal agencies committed to 3DEP will see modest growth in investments in FY15 with accelerated growth thereafter.
- Steady-state operational funding levels will be achieved in FY17.
- Lidar and ifsar collections under the legacy NED program will be included in 3DEP and may or may not be replaced during the ensuing years depending on funding and other factors.
- The planned schedule is based on the assumption that the initiative will be fully funded through data and funds contributed by participating government agencies and tribes; however, if full funding is not achieved, the completion date of the initiative will be extended.

The transition to a steady-state 3DEP operating function was initiated in 2012 with the decision to begin the consolidation and modernization of existing elevation and source lidar and ifsar data activities. The acquisition cost per square mile declined in 2012 and in 2013 as contractors improved their processing software and data-collection platforms. This decline means that lower acquisition cost objectives are already being realized even though the strategy to reduce costs through larger acquisition projects is not fully implemented. The overall program initiative budget will be reevaluated in the future if costs continue to decline.

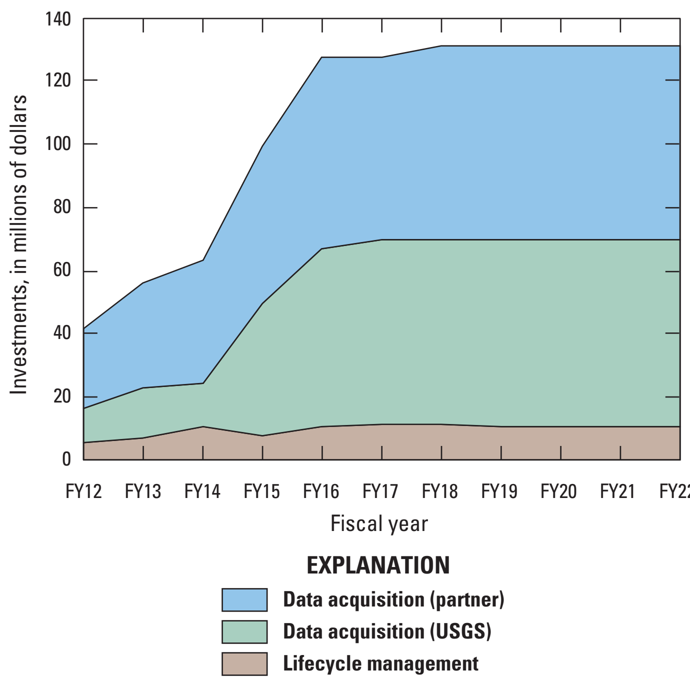


Figure 8. Graph showing one possible funding model (in constant 2012 dollars) for the 3D Elevation Program (3DEP) in 2012–2022. The projected growth model for 3DEP is based on the assumptions that U.S. Geological Survey (USGS) investments will see moderate growth and that investments from partners will show corresponding but lower growth. Total investments from all sources are estimated to be $1,168 million (Dewberry, 2012). In fiscal year 2015 (FY15), 3DEP will become operational, and national coverage is planned for completion in 8 years. This graph excludes $7 million spent on acquiring interferometric synthetic aperture radar (ifsar) data in Alaska prior to 2012.

Source Data, Products, and Services

Users will access and use 3D elevation products and services to directly address their business needs or they will develop other value-added products and services that combine services with other geospatial data and applications. For example, a private company could access lidar classified point cloud data, calculate rooftop solar exposure, and serve the needs of the solar energy industry. Analysts could access 1-meter DEMs and other resource data to run complex flood inundation models to create new flood risk maps. Scientists could use the point cloud data and land cover data to refine their biomass models. These second-tier or advanced uses will be supported by data products and services. The role of 3DEP is not to provide advanced application services but to rely heavily on the private sector and others in government to expand their offerings and to integrate elevation services into their standard business practices. In this model, the private sector's opportunity to innovate and to provide new services is a key benefit of a national 3DEP initiative. The boundary between standard products and services and advanced products and services provided by others will always be inexact, but the general principle is that when a product or service from 3DEP must be combined with other data, it falls outside of the program scope.

The target achievement for 3DEP includes coverage of QL2 lidar data for 49 States and the U.S. territories and QL5 ifsar data for Alaska. For the assumed funding levels, the target would be achieved in 2022. Source data inputs to 3DEP include QL2 lidar full point cloud, orthorectified lidar intensity images, breaklines (if collected for hydro-conditioning), and orthorectified ifsar intensity images. Source data include enhanced spatial metadata. DEMs will be generated from QL2 lidar (conterminous United States, Hawaii, selected areas of Alaska, and territories) or QL5 ifsar (Alaska only) source data and will be hydro-flattened to improve water-feature definition and to represent the topographic surface properly. Digital surface models (DSMs) are deliverables of ifsar acquisition projects and may also be deliverables of lidar projects. Source data and the initial DEMs are generally acquired from the private sector through contracted services. Until national coverage is completed, there will be large areas where QL2 source data are not available. For these areas, the standard products will be composed of legacy data. Existing lidar, ifsar, and NED data will transition to 3DEP and become part of *The National Map* operations. As new data are acquired, they will be used to update the legacy datasets. Older source DEMs will remain accessible as historical data. Definitions of the source data and derived data types can be found in appendix 1.

The source data, as outlined in table 5, will be released upon completion of the phased implementation of the NED, lidar, and ifsar modernization activities. The detailed specifications for the lidar source data and source DEMs acquired between 2012 and 2014 can be found in the "Lidar Base Specification Version 1.0" (Heidemann, 2012). The specifications undergo periodic updates.

For the lidar classified point cloud and DEMs, multiple data products are planned (table 6). For example, the NED consists of 2, 1, 1/3, and 1/9 arc-second DEM products that are tiled for download. The 2 arc-second (Alaska only), 1 arc-second, and 1/3 arc-second DEMs will continue to be

Table 5. Status and planned release dates for source data from the 3D Elevation Program.

[The initial source data offering will include lidar and ifsar data for limited geographic areas. All dates are preliminary and may change. The Earth Resources Observation and Science (EROS) Center provides source data via the EarthExplorer application. The National Geospatial Technical Operations Center (NGTOC) provides source data through *The National Map* delivery services. Special-request products are available by contacting either EROS or NGTOC as indicated in the table. See appendix 1 for source data definitions. Lidar specifications for data collection, classified point cloud, and source digital elevation models (DEMs) acquired between 2012 and 2014 can be found in the "Lidar Base Specification Version 1.0" (Heidemann, 2012). Definitions: ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging; QL, quality level; TBD, to be determined; U.S., United States]

Source data	Planned coverage on release date	Sources	Planned product or service	Planned availability and release dates
Lidar full point cloud—Unclassified	Partial coverage—U.S.	Lidar—QL1, QL2, QL3	Project areas by special request	EROS by special request now (pre-2014 data). NGTOC now (data acquired 2014 and later).
Lidar full point cloud—Classified	Partial coverage—U.S.	Lidar—QL1, QL2, QL3	Project tiles by download	EarthExplorer now. *The National Map* in October 2014.
Ifsar digital surface model	Partial coverage—Alaska	Ifsar—QL5	Project tiles by download	EarthExplorer now. *The National Map* in early 2015.
Orthorectified ifsar intensity image	Partial coverage—Alaska	Ifsar—QL5	Project tiles by download	EarthExplorer now. *The National Map* in early 2015.
Source resolution DEM	Partial coverage—U.S. and some territories	Lidar, ifsar	Project tiles by download	*The National Map* now (new data) and TBD for pre-2014 data.

seamless products created from the source hydrologically flattened DEMs. The 1/9 arc-second product will be managed as a legacy product, and new source DEMs will gradually replace the 1/9 arc-second product with a 1-meter DEM product. A standard 1-meter DEM product will begin production in 2015 for newly acquired data. In addition to these products, a small number of new products may be released as part of the 3DEP standard product and service offering. Such products could include slope models, aspect services, cross-section profiles, breaklines, or others. The NEEA study and input from data users will be the basis for determining future product requirements and preliminary product specifications. An assessment of production feasibility and probable cost will be completed for each proposed product or service.

Although the standard product and service offerings will grow over time, they will be limited to products and services that can be created directly from the source lidar and ifsar data and from the derived DEMs. Standard products will initially be pregenerated to set specifications and limited formats and staged for viewing and download through *The National Map* viewer and download platform. Users will also be able to create their own custom interface to access the visualization and staged product download services. Bulk distribution services are available for large data requests and for some source datasets that are not available through the download platform. As new services are created, they will be accessible in convenient, modifiable, and open formats that can be retrieved, downloaded, indexed, and searched in accordance with Open Government goals (Office of Management and Budget, 2013). A spot-elevation query service will also be available. In 2014 and 2015, on-demand product generation and delivery services will be evaluated in order to provide customers with a richer use experience. Provision of on-demand product services could begin as early as 2015. The provisioning of data-as-a-service is being evaluated and will depend, in part, on the emerging cloud service model and the Geospatial Platform under development by the Federal Government.

Table 6. Status and planned release dates for derived elevation products, including standard digital elevation models (DEMs), and for services of the 3D Elevation Program.

[For the initial standard products, geographic coverage will be limited for many products due to limited availability of source data; all dates are preliminary and may change. The contour interval is dependent on local topographic relief as published on the US Topo map, a georeferenced digital map produced by the U.S. Geological Survey from *The National Map* data. EarthExplorer and *The National Map* products and services are available online. See appendix 1 for definitions and additional specifications. Definitions: AK, Alaska; CONUS, conterminous United States; HI, Hawaii; ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging; TBD, to be determined; U.S., United States]

Product	Planned coverage on release date	Sources	Planned product or service	Planned availability and release dates
1-meter DEM	Partial coverage—U.S. and some territories	Lidar	Tiles (TBD) by download	*The National Map* in early 2015 (new data) and TBD for pre-2014 data
5-meter DEM	Partial coverage—Alaska	Ifsar	1-degree×1-degree block by download	*The National Map* and EarthExplorer now
1/9 arc-second DEM—Legacy	Partial coverage—U.S. and some territories	Lidar, ifsar, photogrammetry	15-minute×15-minute block by download	*The National Map* now
1/3 arc-second DEM	CONUS, HI, some territories, parts of Alaska	Lidar, ifsar, photogrammetry	1-degree×1-degree block by download	*The National Map* now
1 arc-second DEM	CONUS, HI, AK, and U.S. territories	Lidar, ifsar, photogrammetry	1-degree×1-degree block by download	*The National Map* now
2 arc-second DEM	Alaska	Lidar, ifsar, photogrammetry	1-degree×1-degree block by download	*The National Map* now
Elevation-point query	CONUS, HI, some territories, AK	1/3 arc-second DEM, except 1 arc-second DEM in AK	Application service	*The National Map* now
Hillshade	CONUS, HI, some territories, AK	1/3 arc-second DEM, except 1 arc-second DEM in AK	Viewing service	*The National Map* now
Contours at 5 to 120 feet	CONUS, HI, some territories, AK	1/3 arc-second DEM, except 1 arc-second DEM in AK	1-degree×1-degree block by download and viewing service	*The National Map* now

Existing Data and Annual Inventory

An integral part of planning and monitoring the 3DEP data-acquisition effort is the United States Interagency Elevation Inventory (USIEI). The USIEI was developed during the NEEA study to determine the status and availability of high-resolution lidar and ifsar data in the United States. The inventory contains information for both terrestrial and bathymetric data organized by data-acquisition-project boundaries. Since the completion of the NEEA study, the USIEI has been jointly maintained by NOAA and the USGS and has been updated annually. Each year, USGS geospatial liaisons review high-resolution lidar and ifsar projects and provide edits to existing inventory data, as well as new project information (fig. 9). The criteria for inventory are that the lidar or ifsar data need to be publicly available and cover an area that is at least 100 square miles or a full administrative unit. Prior to 2014, the minimum area threshold for the inventory was 300 square miles. The data must be available, under contract, or planned and funded to be included in the inventory. This information is reviewed and refined at the USGS, then provided to NOAA. The resulting inventory data are stored in a format ready for use in a geographic information system (GIS) and are available for download into desktop GIS software for display and analysis. Additionally, NOAA maintains a publicly available Web-based viewer (*http://www.csc.noaa.gov/digitalcoast/tools/inventory*) for quick geographic display of USIEI information. The USGS and NOAA are engaged in ongoing dialogue and coordination efforts to identify process efficiencies for maintaining the USIEI as a viable program-management tool to support 3DEP acquisition planning.

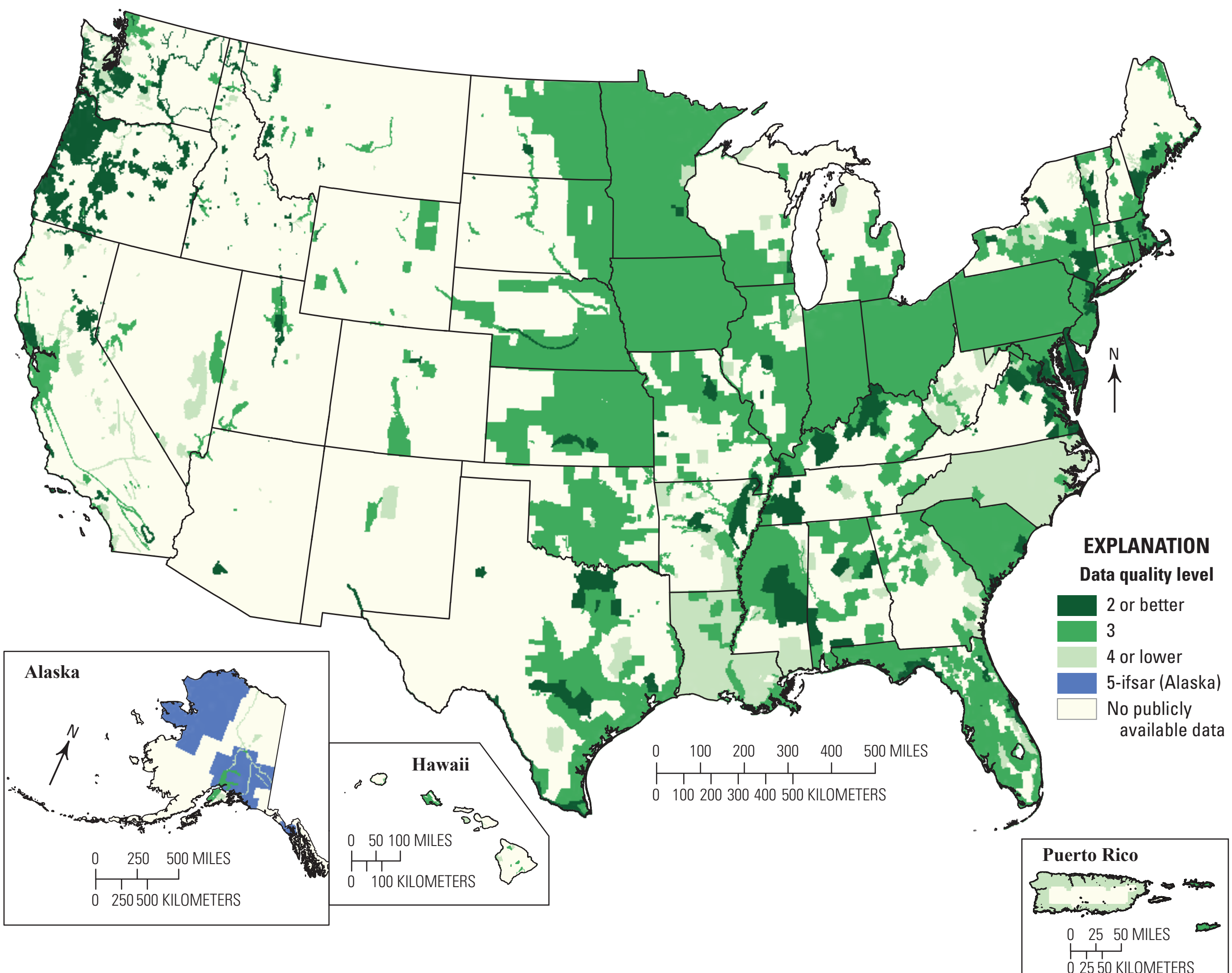


Figure 9. Map of the United States depicting areas for which lidar and ifsar (in Alaska) data of different quality levels were publicly available as of August 2013. The maps include data from projects that were in progress or planned with funding as of 2013. Approximately 4 percent of the conterminous United States plus Hawaii has quality level 2 or better lidar data, and 46 percent of Alaska has ifsar coverage. When all quality levels are considered, 38 percent of the conterminous United States plus Hawaii has lidar data. The average annual collection rate for the United States was approximately 4 to 5 percent per year over the past 4 years (2010–2013). Definitions: ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging.

Data-Acquisition Planning and Partnerships

Acquisition of elevation data has long relied on coordination and partnerships among Federal, State, local, and Tribal organizations. The NDEP has coordinated data acquisition and promoted data sharing to avoid duplication among Federal agencies with varying mission needs and plans. Among the States, there is a wide range of acquisition and partnership strategies at various stages of implementation. Federal, State, local, and other organizations frequently partner on a project-by-project basis to leverage funding and increase coverage areas. In order to achieve national coverage on an aggressive 8-year cycle, the 3DEP initiative must build on existing relationships to establish a systematic and more unified process for data-acquisition partnerships. The USGS will collaborate with Federal, State, and other partners to define a process that will begin to be implemented in FY15 and will evolve as the program matures.

A critical first step in developing a systematic acquisition process is to document and communicate the data needs of the participating partners. The USGS will solicit priorities and plans from Federal and State agencies with a goal of forming a 3-year acquisition strategy. This information will be published and maintained on the 3DEP Web site to increase the potential for identifying common interests and leveraging funds. In FY15, an initial set of Federal agency priorities will inform the acquisition strategy. More comprehensive Federal plans and information about State plans will continue to be sought and refined in subsequent years. The NDEP, and a planned coordinating committee, will review and refine the 3-year strategy annually, or more frequently as needed. The acquisition strategy will seek to expand data coverage in areas where there are multiple requirements and a high potential for leveraging funds and where high benefits were indicated in the NEEA study. In addition, areas with old, low-quality, or no lidar data will be addressed. Areas subject to serious and significant hazards (earthquakes, landslides, volcanic activity, coastal flooding, sea-level rise) may also receive priority among participating partners. Finally, to achieve economies of scale, the strategy will seek to identify areas where combined partner areas of interest are greater than 1,500 square miles.

The USGS issued a Broad Agency Announcement (BAA) in July 2014 to accept partnership proposals. Depending on their needs, partners may propose acquisition projects that use the USGS geospatial products and services contract (GPSC) or their own authorities and contracts to acquire data that meet the 3DEP specification. To ensure data quality and efficient development of standard products and services, the USGS prefers that partners use the GPSC when possible and practical. The BAA, which will be reissued annually, provides detailed instructions for submitting partnership proposals and describes the specific criteria for project selection. Instructions for accessing the current announcement can be found on the 3DEP Web site at *http://nationalmap.gov/3dep/*.

Government agencies and Tribal organizations may also contribute data to the national database that meet 3DEP specifications. These data may be acquired through the USGS GPSC or partner contracts. The USGS will implement a standard procedure for reviewing and accepting the datasets and will provide feedback to contributors on 3DEP production schedules for releasing the data and new derived products. Contributed data will be reported together with data acquired through partnerships in the 3DEP annual report. In addition to contributing to the national strategy, partners will directly benefit by having a backup distribution service for their data.

The data acquisition partnership process will depend on several significant changes to the way coordination and partnerships are implemented today.

- Reporting of priorities will be earlier and more comprehensive—Federal and State agencies will be encouraged to report their data priorities on a cyclical basis. Some agencies currently work on a project-by-project basis, and all agency budgets and plans are subject to change. However, where priorities and plans can be identified, the process will increase efficiency and cost savings to the partnering agencies and contribute to 3DEP coverage goals. Agencies will be encouraged to implement advance planning to the degree possible, depending on their unique situations.
- Federal agencies will be asked to participate on a flexible but unified plan—Mission objectives of the partner agencies for data acquisition must be honored and must drive the acquisition process. Funding from partner agencies will continue to be focused on their specific mission needs, while USGS funding will be used to increase coverage areas around partner projects and, where necessary, quality levels, to meet 3DEP objectives. Mission needs are not a barrier but are central to developing a unified plan that is flexible as budget pictures and mission needs develop and change over time.
- State agencies will be asked for statewide plans and coordination—Because the partnership process will depend on State and regional coordination, the States are encouraged to coordinate with local and other entities to build funding coalitions and plans that feed into the national process, and to ensure that multiple needs are met at that level. The 3DEP planning approach is intended to provide the lead time that States need to enable funding initiatives to be passed in their respective States. The 3-year planning strategy for 3DEP will also, over time, create a more predictable funding source that will provide States further incentives for moving ahead with statewide acquisition strategies and for using the GPSC. Active participation by the States will result in higher quality data overall and will help assure that the objectives of a national strategy can be achieved. USGS geospatial liaisons will provide States with technical assistance when needed and coordination support to facilitate participation in 3DEP data-collection activities.

Federal Roles and Responsibilities

Success of the 3DEP initiative depends on the active support of Federal agencies to fulfill the following roles and responsibilities.

- Federal agencies will coordinate and facilitate development of annual and multiyear plans for their agencies nationally.
- Federal agencies will provide spokespeople and support the 3DEP goal to achieve nationwide 3D elevation data coverage.
- Federal agencies will be members of and participate in the 3DEP coordinating committee planning activities.
- Federal agencies will work in partnership and provide financial contributions to data-acquisition projects or acquire and contribute data that meet 3DEP specifications.

State Roles and Responsibilities

The States are major contributors of data and often lead statewide acquisition programs. The 3DEP planning approach is intended to encourage expansion of State-level partnerships. As a 3DEP initiative participant, each State will have agreed-upon roles and responsibilities. State roles and structures vary across the country. It is incumbent upon the Federal agencies to recognize this and to accommodate the variation that exists. Characteristics of a successful State partnership would likely include the following elements:

- A statewide funding strategy to collect and manage 3D elevation data and funding to participate in partnership activities.
- An outreach strategy supporting the goal of nationwide coverage.
- A program to coordinate and facilitate the development of local and regional partnerships.
- A commitment to meet or exceed 3DEP data-acquisition specifications.

As outlined, the 3DEP data-acquisition partnership approach will be beneficial in the following ways:

- The level of investments will increase, improving cost efficiency of acquisition and providing a greater return on individual agency investments in terms of data coverage and quality.
- Economic benefits directly attributable to high-quality 3D elevation data will be greater and realized sooner.
- The 3-year planning strategy will give the States ample time to prepare budget initiatives and to participate fully in 3DEP.
- Common and standard data-collection specifications will be implemented to ensure that data are compatible and support geographic analyses across State lines and project boundaries.
- The USGS GPSC provides the most consistent and efficient contract mechanism to contribute 3D elevation data to the national collection.
- Large-area data-acquisition projects are consistent with most State plans that have called for statewide coverage to be achieved in 3 to 5 years.
- The patchwork-quilt effect will be minimized through larger area data-collection projects, which accelerate the rate of coverage.
- The higher QL2 data-acquisition specification under 3DEP provides for a lower cost upgrade path for States or other partners that want QL1 data.
- The approach addresses findings in the U.S. Government Accountability Office’s report GAO–13–94 on geospatial information coordination and reducing duplication (U.S. Government Accountability Office, 2012) and fulfills OMB’s requirements (Office of Management and Budget, 2013) for managing National Geospatial Data Assets through a unified and well-communicated process of coordination and partnerships.

Data-Acquisition Contracts and Specifications

Source data will be collected by contractors for the USGS or partner organizations. Data-acquisition projects managed by the USGS use a suite of qualifications-based selection (QBS), indefinite delivery, indefinite quantity (IDIQ) contracts collectively referred to as the geospatial products and services contract (GPSC). There are seven prime contractors under the GPSC, which has a combined delegated procurement authority of $250 million. Each prime contractor has multiple subcontractors on its GPSC team. The contracts include acquisition, processing, and quality assurance of lidar and other source geographic data. The acquisition specification calls for a number of standard deliverables to be created by the contractors to include raw and classified point cloud data, and derived DEMs. These contracts were awarded beginning in the fall of 2009 for one year with four available option years. The GPSC will be recompeted in 2014 to expand the scope of services and increase acquisition capacity for 3DEP. To ensure data quality and standardized product and service development, the USGS prefers that partners use the GPSC to acquire data when possible and practical. While funding partners will be encouraged to utilize the services of the USGS GPSC, they may elect to use their own contracting capabilities. When 3DEP acquisitions are managed through contracts other than the GPSC, the acquiring partner agency will require that the contracted project deliverables meet the minimum 3DEP acquisition specifications and that all mandatory deliverables are provided to the USGS.

Beginning in late 2009, lidar data acquired by the USGS had to meet QL3 requirements prescribed by draft lidar specifications that were later refined for formal publication as the USGS National Geospatial Program's (NGP's) "Lidar Base Specification Version 1.0" (Heidemann, 2012). Use of the specification ensures that the point cloud source data are handled in a consistent manner by all data providers and are delivered to the USGS in clearly defined formats. The minimum specifications under version 1.0 also ensure that bare-earth-surface digital elevation models (DEMs) derived from lidar data are suitable for the NED.

The "Lidar Base Specification Version 1.0" includes mandatory deliverables per project as follows:

- Raw point cloud—Data for each project are collected in swaths, are fully calibrated, are adjusted to match ground control, use a local coordinate reference system, and are unclassified.
- Classified point cloud—Data are provided as project tiles (having no geographic overlap), use a local coordinate reference system, and are classified.
- Bare-earth surface (raster DEM)—Hydro-flattened, topographic DEMs, typically based on a 1-meter grid cell (may also be 3 feet) are derived from the QL3 base specification lidar point cloud.
- Breaklines—If breaklines are used for hydro-flattening, they are included in the deliverables.
- Metadata.

Subsequent to the initial drafting of the version 1.0 specification, a number of significant evolutions have occurred within the lidar industry. The publication of the NEEA study (Dewberry, 2012) prompted adoption by the NGP of QL2 as the minimum accuracy required for 3DEP. The American Society for Photogrammetry and Remote Sensing (ASPRS) undertook a complete revision of its accuracy standards; a draft is available online for review (American Society for Photogrammetry and Remote Sensing, 2014). Alignment with these newly defined standards is all but mandatory for 3DEP. Technical advances in instrumentation and software have changed some aspects of collection and processing of lidar data.

In order to retain currency and relevance, the lidar base specification is being revised. The BAA will be amended to require the new specification when it is publicly released as a USGS publication. The revised specification will reflect these maturations of the industry:

- Specifications are added for QL2 and QL1; a QL0 placeholder is added for potential future improvements in technology and requirements.
- A broader set of detailed requirements is defined for all QLs. For QL2, relative to QL3:
    - Absolute accuracy is improved from ≤18.5 centimeters $RMSE_z$ (root mean square error in the *z* [elevation] dimension) to ≤10 centimeters.
    - Nominal pulse spacing (NPS) is decreased from 2 meters to 0.7 meter.
    - Classification accuracy requirement is increased from 98 to 99 percent.
    - Relative accuracy, within swath and swath-to-swath, is improved from 7 centimeters $RMSD_z$ (root mean square difference in the *z* [elevation] dimension) and 10 centimeters $RMSD_z$ to 3 centimeters $RMSD_z$ and 6 centimeters $RMSD_z$; swath-to-swath differences are now limited to an absolute maximum of 16 centimeters in nonvegetated areas.
- Requirements affected by the draft 2014 "ASPRS Accuracy Standards for Digital Geospatial Data" (American Society for Photogrammetry and Remote Sensing, 2014) are updated:
    - QL definitions are slightly modified to align with the standard ASPRS (2014) accuracy classes.
    - Absolute accuracy assessment is reduced to two broad types: nonvegetated and vegetated.
    - Accuracy checkpoint quantities are tied to project area.
    - Relative accuracy assessment methods are updated.
- Multiple coverage collections are defined.
- LAS specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2013) is required.
- Classification of bridge decks is required.
- Datum and coordinate reference system (CRS) requirements are restated.
- Metadata requirements are expanded to fully support lidar-specific information.

Other revisions and additional requirements being considered for future versions of the "Lidar Base Specification" are as follows:

- Add requirements for tidal coordination for all coastal projects (in coordination with NOAA).
- Adopt new measurement methodology and specifications for relative accuracy being developed by ASPRS (research led by the USGS).
- Adopt ASPRS assessment and reporting practices for lidar horizontal accuracy, once defined (with USGS involvement).

- Require additional classifications of lidar point data to include road surfaces, vegetation (high, medium, and low), buildings and other structures, other landscape features, or "exclusion" classes for points near specific types of breaklines.
- Include appropriate materials to address emerging lidar-collection technologies, such as Geiger (Albota and others, 2002) and Flash (Ramond and others, 2011), as those systems demonstrate commercial capability and delivery of data suitable for 3DEP applications.
- Develop a GIS Data Dictionary defining specifications for collection and delivery of a range of adjunct geospatial data layers.

Information gathered from USGS user communities identified the hydro-enforced DEM as a high-demand derivative product. At this time, however, the procedures for creating this product are not defined sufficiently to create a specification, and the effort is deeply intertwined with USGS research to create an integrated elevation and hydrography data model needed to support advanced analysis. A high-priority research topic has been identified to address this issue. Depending on the outcome of the research activity, a hydro-enforced DEM may become a standard product or it may be added to the specification as an optional upgrade.

Data Quality Control and Acceptance

The USGS performs quality control (QC) inspection of all elevation data to ensure compliance with contract specifications. For data that the USGS receives from other organizations, an assessment is completed to determine whether or not they meet the minimum specifications. The QC includes the following:

- Inspection of all delivered files (lidar and ifsar project and data files, metadata, DEMs, imagery and other required files) to identify corrupt or missing data and improper formats.
- Automated and visual assessment of project and file metadata for completeness and accuracy.
- Visual inspection of DEMs and lidar point cloud data for surface continuity, proper treatment of hydrographic features, vegetation and building removal, point classification, and other characteristics.
- Independent vertical accuracy testing for compliance with specifications.

Projects with missing, inaccurate, or improperly processed data are returned to the contractor with an inspection report identifying and describing the problems (or examples of the problems). Subsequent deliveries are rechecked and accepted if problems are corrected to specification. The USGS may correct minor problems if doing so is more cost effective to the Government. Similar QC checks will continue with 3DEP; however, because the volume of data will be five to six times greater per year than amounts that were quality controlled historically, efficiency improvements are part of the planned data management modernization activities. They include some or all of the following:

- Additional storage, high-performance workstations, and more efficient QC software.
- Design and implementation of a statistically sound QC sampling process.
- Increased automation to identify elevation surface anomalies (for example, poor swath joins or clusters of vegetation or buildings) by using automated surface roughness/continuity analysis.

Elevation data that are contributed to the USGS may require editing to resolve various anomalies in the data. Historically, edited source DEM data were resampled into the 1/9 arc-second dataset. These edited (modified) source data were not retained as they were considered to be intermediate work products. The NED modernization project will change this practice, and source DEM edits will be retained in the future.

Data Processing and Product Creation

The 3DEP operational infrastructure will be established to meet acquisition, processing, information management, and delivery requirements. Figure 10 illustrates the 3DEP concept of operations including acquisition, quality control and acceptance, storage, and processing of data, and creation and delivery of products. Product options and delivery service components will be modified as the product requirements are refined and finalized according to the assessment of users' product needs and according to continued product research.

The USGS will manage source data in the native form (projection, coordinate system, and horizontal post spacing) by project or project tiles for lidar, ifsar, source DEMs, and other data types as delivered by contractors or contributing partners. Customers will generally be able to access these data via online download services. The timing of these services will vary by data type and source data condition. In particular, older dataset quality and completeness are highly variable, and a planned assessment will determine the feasibility of providing future access to those data.

For ifsar data in Alaska and for new lidar data projects acquired to the QL2 specification, all new DEM products will be supported. From ifsar, 5-meter, 1 arc-second, and 2 arc-second DEMs will be created for Alaska. For the conterminous United States and Hawaii, standard 1-meter (beginning in 2015), 1/3 arc-second, and 1 arc-second DEMs will be supported. Support for the 1/9 arc-second DEM will likely be phased out as the 1-meter DEM product becomes available, although legacy 1/9 arc-second data will be retained

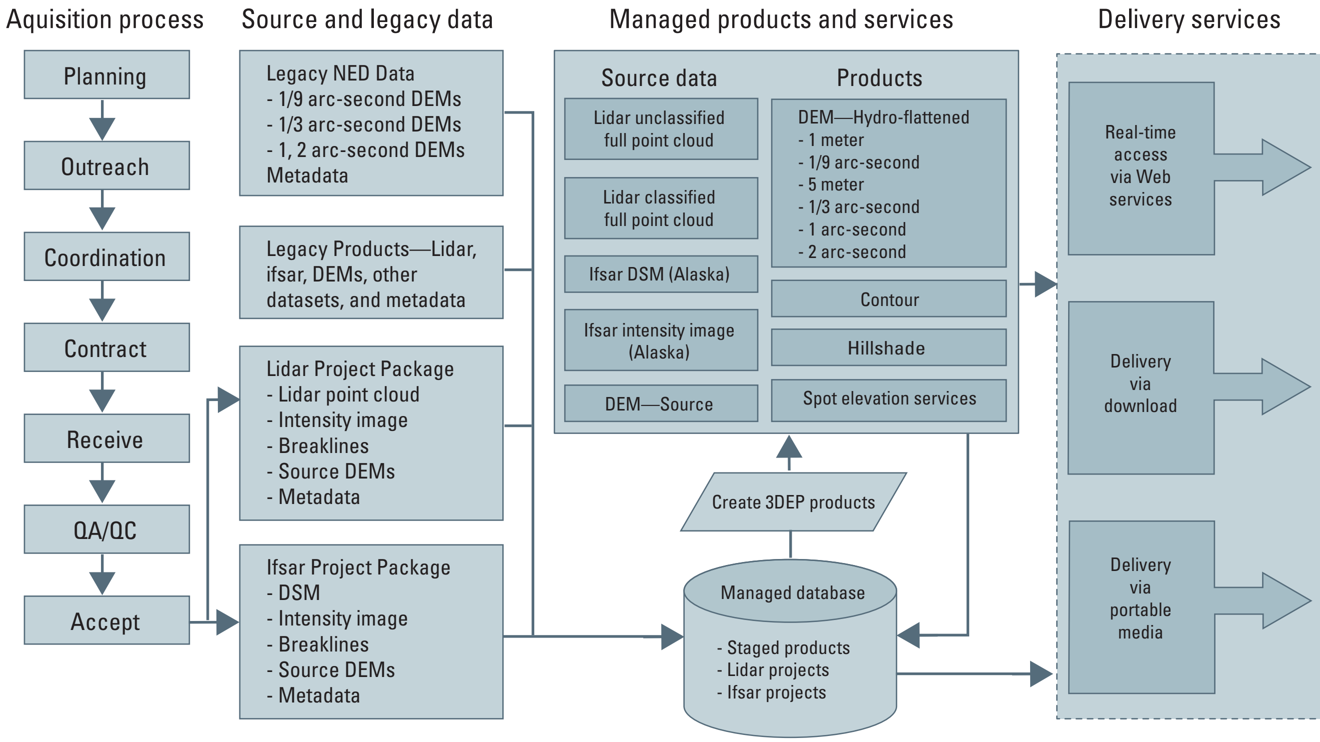


Figure 10. Flowchart illustrating the concept of operations workflow for the 3D Elevation Program (3DEP) as it continues to offer the legacy products of the National Elevation Dataset (NED) and transitions to a new operational state. For details on planned source data and derived products, plus expected delivery dates, see tables 5 and 6. Note that the acquisition steps (column one) may be performed by the U.S. Geological Survey or by partner organizations. Definitions: 3D, three dimensional; DEM, digital elevation model; DSM, digital surface model; ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging; QA/QC, quality assurance and quality control.

and available through download services. Products may be created on demand or staged for public access. The exact mix of staged and on-demand products will be determined on the basis of system performance and storage tradeoff assessments.

Native-resolution DEMs may not be available for all areas of preexisting 1/9 arc-second coverage. The 1/9 arc-second layer is presently created from high-resolution DEMs that have been edited to correct various surface anomalies. These edits are not saved back to the original source DEM; they are only preserved in the 1/9 arc-second data layer. Consequently, the 1/9 arc-second layer may be the only edited and quality-controlled data in those areas. In most cases, however, the unedited higher resolution source data will be available for download. As outlined above, the edited source DEMs will be preserved in the future. Production of a staged 1/9 arc-second DEM will likely be discontinued as newer 1-meter DEMs created from QL2 lidar data become available. This change will reduce the cost of resampling and maintaining the DEMs in a common geographic coordinate system. By storing the data in a native format, users will be able to easily convert the data to meet their application-specific requirements. This ease of conversion will minimize the number of coordinate-system transformations and the errors that might be introduced. Updating the seamless 1/3 arc-second DEMs and deriving custom high-resolution products directly from the original data will also improve the accuracy of those datasets by minimizing resampling errors.

New capability to deliver elevation products is planned for early in 2015 as outlined in table 6. Distribution of the classified point cloud data through *The National Map* is planned to become operational in October 2014. The lidar point cloud will be distributed in the same project tiles and form as they are received from vendors. DEMs will continue to be processed into pretiled, staged files. Hillshades will be retained as a viewing service. The work to refine requirements, as outlined in the NEEA, will result in a set of new products to be included in future product releases. It is expected that two to three new products will become available in 2015 to include a new 1-meter DEM product for new data received after April 2014. The staged files will be accessed through *The National Map* viewer and other Web applications. A high-priority research topic has been identified to evaluate on-demand product generation and delivery services as an alternative to publishing and staging data products for download. Total product lifecycle costs and system performance for the alternative approaches are the primary consideration. A secondary research objective is to determine if quality and product consistency can be maintained without visual inspections or other labor-intensive activities for some derived products. The research findings will have the potential to significantly affect the data and information delivery model in the future.

Phase One—NED, Lidar, and Ifsar Operations Modernization

In phase one of streamlining operations, a modernized production system for updating, managing, and delivering 3DEP products and source data has been deployed. This system utilizes new technologies to improve data handling and production workflow automation. The quality assurance of newly acquired elevation data and the NED update process have also been significantly improved. Query and download services for *The National Map* have been improved and integrated with the NED production process, giving the user the ability to easily discover new updates and immediately download new data. Integration of the production and delivery services allows for new project data to be distributed as soon as they are incorporated into the NED layers, a significant improvement over the bimonthly release cycle it replaced. With this system deployment, DEMs will begin to be distributed at their source resolution, starting with all existing Alaska ifsar source DEMs and followed by 1-meter or higher resolution project DEMs, entered into the NED after April 2014. These improvements are necessary to handle the increased data-acquisition rate and expected data volume. The improvements also make it possible to offer additional 3DEP products and services at a lower cost while still maintaining overall product quality.

By October 2014, new production storage and servers are expected to be installed and operational. This expanded capacity will significantly improve the data quality assurance and NED update processes, reducing the lag time between data acquisition and NED availability. Expanded storage will also enable discovery and download of classified lidar point cloud data through *The National Map* viewer.

Phase Two—3DEP Development

Phase two development will include production of a new NED 1-meter standard DEM. This dataset will possess characteristics similar to the 1/9 arc-second DEMs in that it will be seamless within acquisition project but not across projects. It will contain project data that may spatially overlap. Other specifications for this product, such as projection, coordinate system, and tiling extents will be finalized in 2014. The standard 1-meter DEMs will be made available beginning in 2015. The initial release will be produced from any 1-meter or higher resolution DEMs that were processed into the NED after April 2014. One-meter or higher resolution DEMs processed into the NED prior to April 2014 will be evaluated, and if they meet the minimum acceptance criteria, will be added to this new layer as production capacity allows. The minimum acceptance criteria, which are under development, will be modeled after the 3DEP acquisition specifications but likely at a lower threshold of acceptance given that these datasets already exist. Ifsar-source datasets, to include the digital surface model (DSM) and the orthorectified radar intensity image, will be available for download through *The National Map* viewer in early 2015.

Planned enhancements for 2015 include distribution of all NED data via cloud services and an option for downloading compressed classified lidar point cloud data in an open format. The quality-assurance process for elevation data and the NED update system will be further optimized to reduce the lag between data acquisition and 3DEP distribution. Research will begin in 2015 to determine the feasibility of providing on-demand product generation and delivery capabilities.

Risk-Mitigation Strategies

The 3DEP initiative is designed to minimize risks by building on more than 15 years of experience in acquiring digital elevation data and in utilizing partnerships to achieve the program objectives. Fourteen risk areas were identified during the planning process, and implementation tasks are designed to mitigate risk throughout the plan. The identified risks are as follows:

- Insufficient funding significantly increases the timeframe to achieve national coverage and leaves gaps and areas with lower quality or older data.
- Rate of funding increase is too slow to promote partnerships and large-area collections so that the momentum needed to establish a national program is not achieved, perpetuating the opportunistic, project-based approach for acquiring new data.
- Funds are not allocated to the development of information management or technology infrastructure to meet growing needs.
- Funds are not allocated to meet support staff development and management oversight needs.
- Varying budget cycles among partner agencies impede an effective annual planning and coordinated data-acquisition process.
- Partners resist participating in a unified plan in favor of maintaining their independent plans and processes.
- Lack of national plans and coordination within Federal partner agencies impedes the unified planning process.
- The majority of States are unable to implement State lidar plans, resulting in low participation rates from State partners.
- Different collection strategies and specifications among data collectors results in reduced partnership development (for example, topographic specifications versus topobathymetric specifications within the coastal zone).

- Conflicting priorities for data acquisition (both near term and long term) result in partnership development at a rate too low to achieve a national program.
- User requirements are inadequate to fully define products and services, resulting in unrealized user benefits.
- Products or services are delayed due to resource or technology limitations.
- Information technology acquisition policies or protracted delays in contracting result in significant delays for product rollouts.
- Information technology development falls behind schedule or is technologically flawed.

Strategies for addressing implementation issues that will arise during the course of the program are as follows:

- Strategy 1—The 3DEP executive forum and the coordinating committee including partner organizations will participate in the decisionmaking process.
- Strategy 2—The 3DEP initiative will be designed and executed to scale to any funding level up to the proposed $1.2 billion over 8 years.
- Strategy 3—3DEP partnerships are designed to meet and build on the needs of the contributing agencies; further, participation in the 3DEP initiative is voluntary, reducing risk exposure to any agency's mission-critical activity.
- Strategy 4—Systems development will be managed to small, low-risk projects with usable products for customers at the conclusion of each phase.
- Strategy 5—Information technology investments will be minimized and flexible by utilizing cloud services and taking advantage of lease options when technology or services are acquired.

Research Requirements

The 3DEP planning process identified numerous issues or questions for which additional assessments, evaluations, or research is required. For the purposes of this report, the term "research" has been broadly defined to cover issues and questions that need resolution. The acquisition, processing, archiving, and distribution of data for 3DEP require operational developments and some fundamental and applications research. The 3DEP research needs are being addressed across a number of venues and organizations. Research will be coordinated (1) through the National Geospatial Technical Operations Center (NGTOC) for operational development activities and (2) through the USGS Center of Excellence for Geospatial Information Science (CEGIS) or the broader community of researchers for lidar, ifsar, and elevation products and services. The near-term and immediate need requirements have been identified as high priority. The following list summarizes six high-priority and four medium-priority tasks and four long-term research priorities.

1. High priority—Evaluate on-demand product generation and delivery services as an alternative to publishing and staging data products for download. Total product lifecycle costs and system performance for the alternative approaches are the primary consideration. A secondary research objective is to determine if quality and product consistency can be maintained without visual inspections or other labor-intensive activities for some derived products.
2. High priority—Acquire or develop data-management solutions for lidar point cloud files. Evaluate alternative data-management and product-generation systems for lidar data and lidar derivative products. This evaluation may include existing vendor products or a mix of vendor and newly developed capabilities for managing and generating products directly from compressed lidar files. Assessment criteria will include the ability to handle the projected 3DEP data volumes, new product types, and system performance.
3. High priority—Determine which legacy high-resolution source DEMs could be provided. Evaluate alternative solutions, probable costs, and benefits of releasing pre-2014 source DEMs. These DEMs were used to produce lower resolution 1/9 arc-second DEMs and were not maintained as edited source DEMs. The evaluators will consider which source DEMs should be provided on the basis of their quality and age.
4. High priority—Create a specification for a hydrologically enforced DEM and production procedures that will address the primary needs of hydrologists. Hydrologically enforced or conditioned DEMs have been identified as one of the highest priority new products. A hydrologically enforced DEM is required to support hydrologic modeling and mapping requirements. This research objective is significant in that it has the potential to affect the acquisition requirements (and costs) for lidar, ifsar, and the derived DEM products.
5. High priority—Research ways to improve the integration of elevation and hydrography data. A range of alternative solutions will be considered to include new edit tools to align hydrography features with elevation data and advanced data models and procedures to create derived hydrographic networks that are integrated with elevation data.

6. High priority—Research the utility and evaluate new technologies that could be used as data-collection mechanisms for 3DEP in the future. These technologies include, but are not limited to, (1) maturing range detection capabilities such as waveform digitization (Harding and others, 1994), Geiger-mode avalanche photodiodes (Aull and others, 2004), photon-counting detectors (Priedhorsky and others, 1996), and flash arrays (Bulyshev and others, 2009); (2) maturing laser capabilities such as green lasers (Brock and others, 2004), multiwavelength lasers (Wei and others, 2012), and polarimetric filters (Tan and Narayanan, 2004); and (3) potential lidar collection platforms such as satellites, balloons, blimps, unmanned aerial systems, and mobile mapping systems on cars or boats. In addition, increase research on evaluating passive imaging technologies such as machine vision, structure from motion, stereo compilation, and others that may be able to produce 3D information of comparable quality and character as current commercial lidar point clouds.

7. Medium priority—Design a strategy to implement ongoing changes to the National Spatial Reference System (NSRS), which includes geoid models being developed by the National Geodetic Survey (NGS) of NOAA out of the Gravity for the Redefinition of the American Vertical Datum (GRAV–D) program. Planned adjustments to the NSRS will have significant effects on the elevation values. If data will be stored as received, then processing will need to occur to account for the differences in ellipsoids and geoid models used. The horizontal and vertical datums will change significantly in 2022. Data collected over the next 8 years must have metadata necessary to convert the database to the 2022 datums. Ongoing collaboration between the USGS and the NGS is a necessary part of this research objective.

8. Medium priority—Evaluate data-as-a-service solutions for 3D elevation data. The emerging Geospatial Platform and cloud services capabilities offer opportunities for customers to acquire data services rather than building many single-use solutions. The Geospatial Platform was developed by member agencies of the Federal Geographic Data Committee and is available at *https://geoplatform.gov/*. Policy issues with respect to cost recovery (who pays) will be addressed as part of this research topic.

9. Medium priority—Determine user requirements for seamless 1-meter DEMs and other products derived from lidar point cloud data for user-defined areas of interest that cross (acquisition) project boundaries. If required, determine the availability of geoprocessing tools and data-management capabilities for rendering such products efficiently.

10. Medium priority—Determine which products will be standard. The standard suite of 3DEP products derived from lidar point clouds will be identified from the ongoing user requirements assessments. Some products, such as hillshades, slope, and aspect, can be readily produced by using commercial software and require research only to make them operational in a national context. Others may require research and development. This research need is expected to be ongoing as the program changes over time.

11. Long-term research priority—Explore high-performance computing (HPC) and Cyber GIS to support lidar and 3DEP processing; investigate big data approaches with lidar and 3DEP and integration with other USGS science data. Advances in HPC, including parallel processing, grid computing, and cloud-based computational solutions, may provide an opportunity to handle the complex computations and massive volumes of data from 3DEP.

12. Long-term research priority—Evaluate spatiotemporal data models that support the *x, y,* and *z* coordinates available from 3DEP data and also support integration with legacy datasets of hydrography, transportation, and other topographic data. This longer term research objective, while broader, relates to the elevation and hydrography integration objective.

13. Long-term research priority—Identify relations between map scale and geomorphological characteristics of cartographic features to automate extraction and generalization of hydrographic and elevation features. This research objective applies to other feature types found in *The National Map* as well.

14. Long-term research priority—Develop methods, tools, processes, and systems to support use of lidar and other elevation products to support science and other activities. The impacts of 3DEP data resolution on current scientific models are unknown.

Conclusions

The 3D Elevation Program is a nationwide effort to accelerate the collection of 3D elevation data, to manage the authoritative lidar and ifsar datasets, and to provide source data and elevation data products and services to everyone. Although the program is in an early development phase, significant progress is being made on every planned objective. The modernization of data systems is on schedule. Data-collection budgets are increasing. Three Federal agencies have decided to pool funds and to further coordinate their data-collection activities. A new data-acquisition process will allow partner organizations to easily understand the 3DEP priorities and become part of the national plan to refresh all of the 3D elevation data over the next 8 years. The executive forum is established, and the leaders of member agencies are actively working toward full implementation of 3DEP. The program, as defined, is a logical evolution of products and services of *The National Map* and fulfills a major objective of the National Geospatial Program's strategic plan. The USGS is providing the leadership that is needed to achieve the objectives as outlined in the plan described in this report. An annual report will track the progress that is being made toward full implementation of 3DEP.

The 3D Elevation Program is more than a vision. The program to collect 3D elevation data is built on the successful coordination by the National Digital Elevation Program committee and its member agencies that resulted in the National Elevation Dataset. Several of those agencies sponsored the National Enhanced Elevation Assessment in 2010, during which 602 mission-critical activities were identified by 34 Federal agencies, 50 States, local and Tribal governments, and a sample of private industries (Dewberry, 2012). When 3D elevation data from 3DEP are made available as a public service, they will likely generate $690 million per year in new benefits and potentially significantly more.

This report is a "call for action" because there is much to be done. Partner organizations are contributing data and funds valued at $50 million annually today; to achieve the 3DEP goal in 8 years, investments from all sources in data and systems must continue to rise. The private sector provides data-collection, data-processing, and geospatial technologies, and improvements are eagerly anticipated for those systems that are critically important to the advancement of 3DEP. The large community of geospatial data users will need to embrace 3D mapping and apply creative solutions to address the Nation's needs in many arenas, including environmental analysis, resource management, alternative energy development, precision agriculture, and hazards risk assessment and response. This plan will guide the next development steps, and we hope that it will inspire others to join the many government agencies and private companies that are already working to implement 3DEP. By using 3D elevation data in their business practices, the government and private sectors will realize benefits that, in turn, build new support for 3DEP.

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Appendix 1. Definitions of Source Data, Elevation Models, and Other Derivative Products

This appendix defines (1) source data from which elevation models and other derivative products are made, (2) different types of elevation models, and (3) other derivative products created from the source data or elevation models. The derivatives described are being considered as potential products of the 3D Elevation Program (3DEP). With regard to 3DEP, elevation data come from two primary remote-sensing technologies: lidar and ifsar. Although digital elevation models (DEMs) can be generated from data collected by either system, the technologies and their source data are quite different.

Source Data

Source data are the raw data from which elevation models and other derivatives are created. Characteristics of source data are summarized in table 1–1, and the terms therein are described in the section following the table. Data will initially be provided in high-demand proprietary formats and some open formats; the use of open formats will increase as production capability allows.

Table 1–1. Source data details.

Source data type[1]	Potential coverage area[2]	Format[3]
Lidar point cloud	CONUS, HI, territories; small areas in AK	LAS or LAZ
Lidar waveform	CONUS, HI, territories; small areas in AK	LAS and WPD
Breaklines	CONUS, HI, AK, territories	Shapefile or File geodatabase
Ifsar elevation models and imagery	AK	IMG or TIF

[1]Ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging.

[2]AK, Alaska; CONUS, conterminous United States; HI, Hawaii.

[3]Data formats are described in this appendix.

Discrete Lidar

Lidar (light detection and ranging) technology uses a pulsing laser and produces a dataset composed of millions of *x*, *y*, *z* points, each a reflection of the laser pulse from the Earth's surface or other features. These features may include towers, bridges or other elevated structures, rooftops, tree branches and leaves, powerlines, or any physical object visible from above. Using its own laser light source, lidar can illuminate and detect features that would be invisible in traditional aerial imagery because of shadows in vegetation. Each pulse from the laser can produce multiple reflections (points); these are broadly described as single, first, intermediate, or last returns, and the points also have a variety of nongeometric attributes (for example, intensity, scan angle, and scan direction). Discrete lidar refers to lidar point cloud data, as opposed to waveforms (discussed in the following section).

Lidar Point Cloud—Unclassified (Swaths)

Once collected, the recorded signals from the lidar instrument are preprocessed to create the initial lidar full point cloud, geometrically calibrated, and adjusted to match ground control. Individual points already include the various attributes described above but are not yet classified (see below). The data are organized by flightline; each flightline's data are collectively known as a swath. Swath data files can be extremely large. In this form, the positionally correct point cloud data are used for assessment of accuracy and geometric integrity prior to further processing.

Lidar Point Cloud—Classified (Tiles)

During postprocessing, lidar points are classified by the type of object that produced the reflection. Common classifications include bare-earth terrain, water, noise, vegetation, buildings, and other manmade features or objects of interest. The ability to differentiate among these features in the point cloud makes it possible to extract elevation models and numerous additional products from the point cloud. Because the classification process requires some manual interaction, swath files are usually cut into tiles for manageability. These classified tiles are the most familiar and usable form of lidar.

Waveform Lidar

Some lidar systems produce and record a complete waveform of the reflected laser pulse. Analysis of waveform lidar is complex and requires special software and knowledge, but the additional data can provide extremely rich information, particularly for scientific research. In commercial practice, the discrete single, first, intermediate, and last return points are routinely derived from the full waveform data that are processed and delivered as described above for discrete lidar data. The waveform data are stored in separate files, which are included as part of the required project deliverables.

Ifsar

Ifsar (interferometric synthetic aperture radar) uses pulsed radio waves and analyzes differences between the emitted and reflected waveforms. From these analyses, elevation and intensity models are derived directly. Unlike lidar and its point cloud, ifsar's initial source data and its primary derivative models (elevation surfaces and intensity images) are one and the same. These data are described further in the sections on elevation models and other derivatives.

Breaklines

Breaklines are vector lines and polygons that define distinct linear changes in the topography or relevant features that would not be adequately represented or captured in lidar or ifsar data. Examples include ridges, drainage features, retaining walls, culverts, and shorelines. Breaklines can be either two dimensional (2D), with *x, y* coordinates only, or three dimensional (3D), with *x, y* coordinates plus *z* values representing elevations. The 2D breaklines may have a single elevation assigned as an attribute; for example, the shoreline of a still-water lake. Breaklines can be developed through any number of techniques and may be based on the lidar or ifsar data or on other ancillary data sources. Breaklines can be used to supplement the lidar and ifsar data in describing the landform and to facilitate various hydrologic treatments of the DEM surface. The U.S. Geological Survey (USGS) requires collection and delivery of breaklines for all water features that are hydro-flattened in delivered DEMs.

Enhanced Spatial Metadata

Most lidar and ifsar datasets are collected using airborne equipment along parallel overlapping flightlines. Each takeoff and landing cycle of the survey aircraft is called a lift. The data are then organized and processed first by lift and then by flightline. The fundamental characteristics of the data are defined within these individual units. The tiles produced from the flightline swaths inherit those same characteristics. Metadata will therefore document spatial data by project and by lift; tiles will reference the metadata of their parent flightlines and lifts. As a result, the project metadata will record and preserve information for the entire collection and will be a thorough summary of the project.

For data delivered in orthometric heights, the metadata will specify the geoid model used to convert from ellipsoid heights to orthometric heights. Providing this information will enable users to readjust the data to newly adopted and more accurate geoid models.

Data Formats

The terms used in tables 1–1 and 1–2 to describe data formats are defined below.

LAS: The LAS file format is a public file format for the interchange of three-dimensional point cloud data. This binary file format is an alternative to proprietary systems or a generic ASCII file interchange system. The LAS 1.4 specification was approved by the ASPRS Board on November 14, 2011, and is the most recent approved version of the document (American Society for Photogrammetry and Remote Sensing, 2013). LAS files use the ".las" extension.

WPD: LAS version 1.3 introduced the storage of full "waveform" data to the specification. The capability continues unchanged in the LAS 1.4 specification. A waveform is a digitized representation of the complete reflected intensity of a laser pulse with respect to time. The digitized waveforms may be stored within the .las file or as a separate companion file with the extension ".wpd" (for waveform packet data). Because waveform data substantially increase the size of a LAS file, the USGS requires use of the external .wpd files if waveform data are delivered.

LAZ: The LAZ file format is a public file format for the compression of LAS files, typically allowing 80 to 90 percent compression. Many lidar software applications can operate on LAZ files directly (without having to decompress the file).

Shapefile: The Esri shapefile, or simply shapefile, is a popular geospatial vector data format for geographic information system (GIS) software. Developed, maintained, and published by Esri, the format allows interchange and use of data across a wide variety of GIS and computer-aided-design (CAD) software applications. Shapefiles spatially describe vector features: points, lines, and polygons, representing, for example, water wells, rivers, and lakes. Each item has attributes that describe it, such as name or temperature. A shapefile consists of separate files with the same name and different extensions; four files are mandatory (.shp, .shx, .dbf, .prj), but numerous other files may be included to augment the core data files.

File geodatabase: The file geodatabase is an Esri proprietary format for storing almost every type of spatial data (with all attributes and metadata) supported by ArcGIS software. It consists of a file folder containing numerous data files. The structure allows multiple spatial datasets of different types to easily be packaged and shared. A file geodatabase folder name ends with the ".gdb" extension.

GeoTIFF: A public domain metadata standard called GeoTIFF allows georeferencing information to be embedded within a TIFF file. The potential additional information includes map projection, coordinate systems, ellipsoids, datums, and all additional information necessary to establish the exact spatial reference for the data. The GeoTIFF format is fully compliant with TIFF 6.0, so software incapable of reading and interpreting the specialized metadata will still be able to open a GeoTIFF format file. GeoTIFF image files also use the standard ".tif" extension.

IMG: The "Imagine" file format is a semi-open image format developed by ERDAS as the native format for its Imagine software. Although the format's structure is proprietary, there are freely available software libraries for reading and writing the files, and their use is widespread. IMG files offer some notable advantages over other formats: a lack of any file size limit, a standard method for defining blank areas within the image, and the storage of all information related to the image within a single file. Imagine files use the ".img" extension.

Esri GRID: The "GRID" file format is a proprietary legacy raster format developed by Esri as the native format for its Arc/INFO software. GRID raster data are stored in a collection of files and shared folders, and can be awkward to transfer between users. Although the format's structure is proprietary, there are freely available software libraries for reading and writing the files, and the use of the format is ingrained throughout the ArcGIS community.

Esri FLT: The FLT format is a basic generic raster exchange file format. "FLT" is a shorthand name for the Esri-developed "floating point and header file." The published format uses a simple floating-point binary structure for the raster data (the ".flt" file), and a readable ASCII header file (the ".hdr" file) containing requisite information on the structure of the .flt file. Both files are required, as well as external definition of the data's projection.

Elevation Models

A variety of digital models are used to depict the Earth's surface and features on it; models may represent the bare-earth surface (minus vegetation and structures), the surface with vegetation and structures, or the surface with various other modifications (described below). Surface models are most commonly stored and used as a raster dataset. Raster elevation models are much like images, but store elevations (z values) at regularly spaced intervals (cells or pixels) rather than storing reflected light intensity. Table 1–2 lists characteristics of elevation models being considered as potential products of 3DEP. The current standard product of the National Elevation Dataset (NED) is a hydro-flattened digital elevation model (DEM). In addition to these downloadable products, we also will be providing bare-earth data via a Web Coverage Service (WCS), which allows users to save raster products directly to their computers. Supported output formats for WCS are GeoTIFF, NITF, HDF, JPEG, JPEG2000, and PNG.

Table 1–2. Digital elevation model (DEM) product details.

DEM resolution[1]	Cross-project edge matching[2]	Potential coverage area[3]	3DEP source[4]	Format[5]
Source	No	CONUS, HI, AK, territories	Lidar or ifsar	Esri GRID and IMG
1 meter	No	CONUS, HI, territories; small areas in AK	Lidar	Esri GRID and IMG
3 meters	No	CONUS, HI, territories; small areas in AK	Lidar	Esri GRID and IMG
5 meters	No	AK	Ifsar	Esri GRID and IMG
1/3 arc-second (~10 meters)	Yes	CONUS, HI, AK, territories	Lidar or ifsar	Esri GRID, Esri FLT, and IMG
1 arc-second (~30 meters)	Yes	CONUS, HI, AK, territories	Lidar or ifsar	Esri GRID, Esri FLT, and IMG
2 arc-second (~60 meters)	Yes	AK	Ifsar	Esri GRID, Esri FLT, and IMG

[1]An arc-second is 1/3600th of a degree and is the measurement unit in latitude/longitude coordinate systems.

[2]Tiles are edge matched within each collection project.

[3]AK, Alaska; CONUS, conterminous United States; HI, Hawaii.

[4]Ifsar, interferometric synthetic aperture radar; lidar, light detection and ranging.

[5]Data formats are described in this appendix.

Digital Elevation Model (DEM)—No Hydro Treatment

In its simplest form, a DEM is a raster dataset of bare-earth elevations without any additional or special treatment of hydrologic features in the landscape. Bridges are typically removed, but roads over culverts remain in the surface model. These DEMs are used for general topographic mapping. Because 'DEM' is also a broad generic term, this basic type of DEM is denoted as "no hydro treatment" to prevent confusion.

Digital Elevation Model (DEM)—Hydro-Flattened

A hydro-flattened DEM is a raster dataset of bare-earth elevations where the surfaces of ponds and lakes are flattened and leveled, and the surfaces of wider streams and rivers are flattened bank-to-bank and modified to depict continuous downhill flow. Bridge decks are typically removed, but roads over culverts remain in the surface model. Hydro-flattened DEMs are used for general topographic mapping and contour generation.

Digital Elevation Model (DEM)—Hydro-Enforced

A hydro-enforced DEM possesses all of the characteristics of a hydro-flattened DEM, with additional treatments to ensure that drainage features exhibit continuous downhill flow. Notably, this process includes cutting drainage paths across road fills over culverts so the surface depicts the water flow under the road, and it may also remove smaller undulations along narrower stream paths to ensure a downhill gradient. Hydro-enforced DEMs are used for many forms of hydrologic and hydraulic modeling.

Digital Elevation Model (DEM)—Hydro-Conditioned

A hydro-conditioned DEM possesses all of the characteristics of a hydro-enforced DEM with further adjustments of the data. Spurious surface pits and depressions in the surface are removed (filled), allowing continuous water flow across the entire surface. Hydro-conditioned DEMs are used for many forms of hydrologic and hydraulic modeling.

Digital Terrain Model (DTM)

A digital terrain model (DTM) is a representation of a bare-earth surface that includes irregularly spaced mass points and breaklines. The bare-earth points and breaklines as described in the USGS “Lidar Base Specification” (Heidemann, 2012) compose a DTM. Although both model the bare-earth terrain, a DTM differs substantially from a DEM in that the DEM is inherently realized as raster surface model; the mass points and breaklines of a DTM do not form a surface unless first converted into a triangulated irregular network (TIN) or a DEM.

Digital Surface Model (DSM)

A digital surface model (DSM) is a raster surface grid of elevations. Unlike the various types of DEMs, a DSM is a model of the top reflective surface and may include buildings, trees, towers, and other features elevated above the earth, as well as the bare-earth surface in open terrain. The first returns in the lidar point cloud yield a DSM; ifsar data processing can also be optimized to produce a DSM. DSMs are standard deliverables of the Alaska ifsar acquisition projects.

Height Above Ground (HAG)

The height above ground (HAG) is the elevation difference between the highest detected point in a cell and the ground elevation for that cell. This height is obtained simply by a raster calculation where a DEM elevation is subtracted from the DSM elevation. This calculation provides the height of features above the ground. Tree-canopy heights and building footprints and heights can easily be extracted from this derivative. HAG raster models are usually coarser resolution than their source DEM and DSM.

Other Derivative Products

Lidar Intensity Images

A lidar intensity image depicts the strength of the signal reflection from the target(s) back to the lidar instrument as a gray-scale raster image. Intensity images are useful because their inherent orthorectification and georeferencing allow for photogrammetric-like stereo compilation of breaklines and other features. Currently there is no standardized method for calibrating or normalizing an intensity image, which means different objects of the same type may appear with a different brightness, depending on a wide range of factors including flying height, beam divergence, and scan angle.

Ifsar Intensity Images

Ifsar intensity images depict the radar reflectance intensity of various earth-surface materials. Like the lidar intensity images, ifsar images are inherently orthorectified and georeferenced. Ifsar images are standard deliverables of the Alaska ifsar acquisition projects.

Contours

Contours represent lines of equal elevation on the Earth's surface. Although there are multiple methodologies for creating contours, they are typically derived from DEM surfaces; hydro-flattened DEMs are the most suitable type of elevation surface for this purpose. The USGS presently produces and distributes contours at elevation intervals appropriate for terrain depiction at a scale of 1:24,000 and at selected smaller scales. Future services could allow contours to be generated at user-specified intervals for viewing and download.

Cross Section or Profile

A cross section is a side view of a dataset. A cross section of a surface has zero depth. It is geometrically a vertical plane. A cross section of a point cloud has a user-defined depth. When working with point clouds, the depth must be chosen carefully: deep cross sections can be misleading or uninformative as they include points both close to the view and at a greater distance; very shallow cross sections may not capture enough points to present a complete picture.

A profile is the line representing the intersection of a surface and a zero-depth cross-section plane. Cross sections are visual pictures; profiles are data that can be extracted and used in further modeling.

Density (of Lidar Returns)

The density is a raster surface representing the number of returned laser signals within, or within a distance of each pixel. These may be based on the number of first returns (useful to verify coverage and proper mission planning), ground returns (useful for identifying lower confidence areas in the DEM), all returns (useful for assessing vegetation density and land cover types), or other point types and combinations.

Hillshade

Hillshades are 2D gray-scale or color-ramp images that simulate a 3D visualization of the terrain. They may be generated by using variable view angles and sun angles in order to maximize visual interpretability of the terrain. Hillshades are an alternative to contours for human visualization of 3D topographic surfaces; however, they do not provide any actual elevation information. Hillshades are typically derived from bare-earth surfaces but can also be produced from DSMs in order to visualize the terrain with elevated features such as vegetation and manmade structures. Hillshade images are sometimes called “shaded-relief images.”

Aspect

Aspect is the compass direction, normally measured clockwise in degrees from north, that each pixel in an elevation surface faces. Aspect datasets are derived as rasters from a DEM.

Curvature

Curvature is a raster elevation derivative that defines the shape of the terrain surface for analysis of surface-flow pathways and soil wetness, for example. There are nine basic curvature types that are combined for many types of curvature analyses; for example, plan form curvature, profile curvature, and tangential curvature.

Slope

Slope is the measure of change in elevation over distance, expressed either in degrees or as a percent; the slope is measured either from a TIN or from a raster dataset. Slope maps may be derived as raster datasets from DEMs.

Flow Direction

A flow-direction surface depicts the steepest downhill path for each cell in a DEM. The direction is a value coded to one of the cell’s eight neighboring cells. It identifies each cell’s lowest neighbor. Flow direction surfaces are fundamental models for numerous hydrologic analyses.

Flow Accumulation

A flow-accumulation model is derived from the flow-direction surface. It represents the number of “upstream” DEM points whose flow path passes through it. High accumulation values indicate points in a stream, whereas low values represent areas of overland flow. Depending on the quality and detail of the original DEM, detailed stream networks can be derived from the flow accumulation model.

Back cover:

Top: A lidar point cloud of part of San Francisco Bay and the Golden Gate Bridge, California; the view is toward the south-southwest. Data were collected in 2010 by an airborne lidar (light detection and ranging) instrument. San Francisco State University acquired the data in cooperation with the U.S. Geological Survey, and the work was funded by the American Recovery and Reinvestment Act (ARRA) of 2009. Points are colored by elevation from low (blue) to high (red).

Bottom: A lidar point cloud of the Gateway Arch and part of St. Louis, Missouri; the view is toward the west. Data were collected in 2012 by an airborne lidar (light detection and ranging) instrument. The U.S. Army Corps of Engineers (USACE) acquired the data in partnership with the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture, the U.S. Geological Survey (USGS), Missouri's State Emergency Management Agency (SEMA), the Metropolitan St. Louis Sewer District (MSD), and the Missouri Department of Natural Resources (MoDNR). Detailed ground elevation data for approximately 6,287 square miles were compiled during a unified collection and processing project. Points are colored by elevation from low (blue) to high (red).

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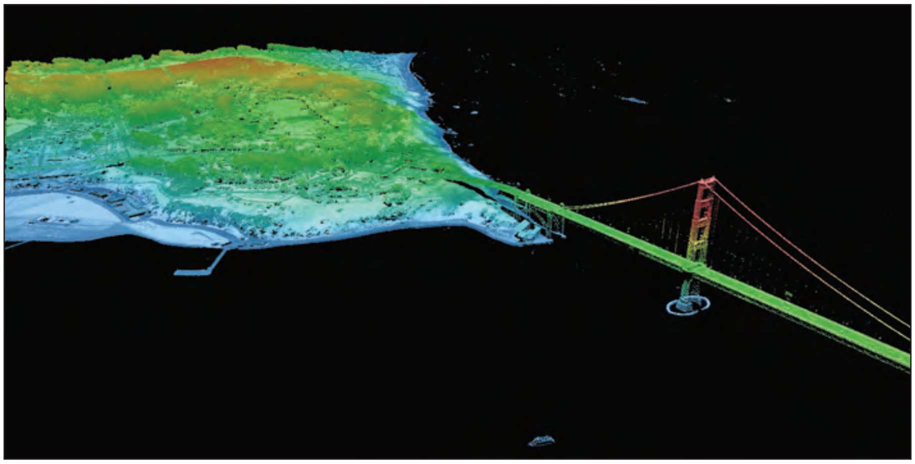

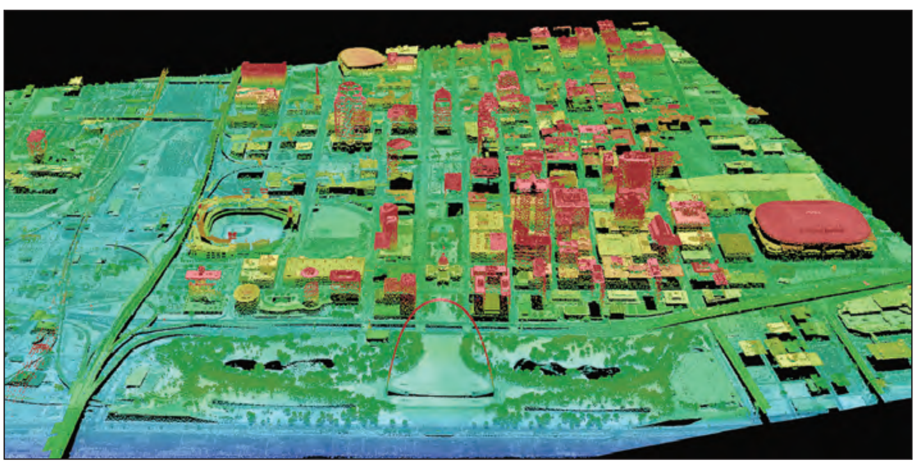

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