The 3D Elevation Program—Flood Risk Management

Flood Hazard to Flood Risk

Over the last 30 years, on average, flooding has cost the United States nearly $8 billion annually and has resulted in more than 80 fatalities per year, according to the National Oceanic and Atmospheric Administration (NOAA), National Weather Service Hydrologic Information Center (www.nws.noaa.gov/hic/) (NOAA, 2015). Flooding is the leading cause of Presidential disaster declarations.

Flood-damage reduction has been a longstanding but elusive societal goal. The national strategy for reducing flood damage has shifted over recent decades from a focus on construction of flood-control dams and levee systems to a three-pronged strategy to (1) improve the design and operation of such structures, (2) provide more accurate and accessible flood forecasting, and (3) shift the Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) to a more balanced, less costly flood-insurance paradigm (http://www.fema.gov/policy-claim-statistics-flood-insurance) (FEMA, 2017). Expanding the availability and use of high-quality, three-dimensional (3D) elevation information derived from modern light detection and ranging (lidar) technologies to provide essential terrain data poses a singular opportunity to dramatically enhance the effectiveness of all three components of this strategy.

The U.S. Geological Survey (USGS) 3D Elevation Program (3DEP) (Sugarbaker and others, 2014; see 3D Elevation Program sidebar) has the programmatic infrastructure to produce and provide the essential terrain data. This infrastructure includes (1) data acquisition partnerships that leverage funding and reduce duplicative efforts, (2) contracts with experienced private mapping firms that ensure acquisition of consistent, low-cost 3D elevation data, and (3) the technical expertise, standards, and specifications required for consistent, edge-to-edge
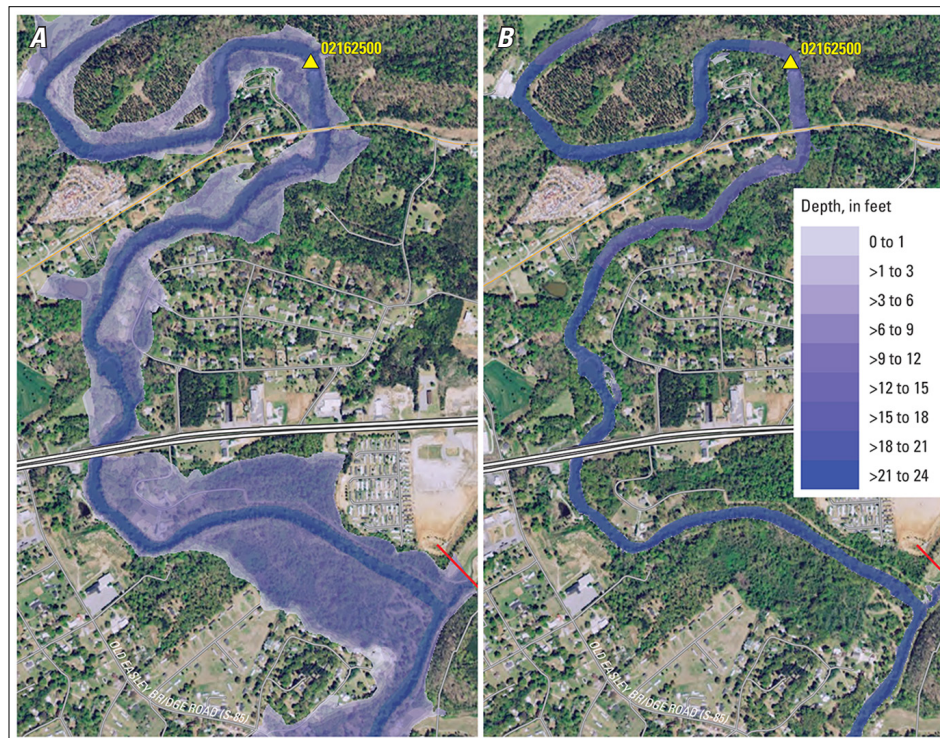

Figure 1. U.S. Geological Survey (USGS) flood-inundation maps for a 3.95-mile reach of the Saluda River near Greenville, South Carolina, originating approximately 150 feet downstream from Saluda Lake Dam. A lidar-derived digital elevation model was used to aid in hydraulic modeling to create these maps. The extent of inundation depicted corresponds to river stages of 20.0 feet (*A*) and 6.0 feet (*B*) at USGS streamgage 02162500 (yellow triangle) on the Saluda River. The red line corresponds to the model extent.

A flood-inundation map minimally shows the extent of flooding for a stream reach and also includes depths of floodwaters where appropriate (fig. 1). The extent and depth of flooding are normally estimated using riverine hydraulic models that take into account streamflows, channel geometry, flood-plain topography, and artificial structures such as bridges and levees. There are many methods to create flood-inundation maps, and they all vary in accuracy and applicability. The USGS has developed and enhanced several methods for map creation and display. The USGS Flood Inundation Mapping Program is discussed at https://water.usgs.gov/osw/flood_inundation/

utility across multiple collection platforms and public access unfettered by individual database designs and limitations.

Flood risk management was identified by the National Enhanced Elevation Assessment (Dewberry, 2012) as one of 27 business uses requiring enhanced elevation data. The assessment cited that some of the uses of 3D elevation data for the flood risk management business use include:

- Enabling the production of much higher quality flood maps (fig. 1), including documentation studies and Flood Insurance Rate Maps (FIRMs).

- Managing dam and levee safety programs that reduce flood risks.

- Improving hydrologic modeling and flood forecasting for emergency management.

- Improving State and local government risk management and flood response.

- Improving regional and local government emergency management and floodplain and stormwater management.

- Improving the design of stormwater drainage facilities and dams.

USGS Streamflow and 3DEP Data Support Flood Risk Management

Investments in flood-control measures, flood forecasting, and flood-insurance programs are required for effective flood risk management. However, an important principle in flood risk management is that flood disasters will continue to occur and that residual flood risk will always remain despite these investments. Nevertheless, disasters can be informative, if society learns the lessons they teach. Learning those lessons effectively means that floods must be understood and documented wherever and whenever they occur. An important tool for preserving flood information is the flood documentation map. Together, FEMA and the USGS have undertaken an extensive, though largely piecemeal program that involves deployment of USGS stream

hydrographers to map flood elevations and the extent of major floods. 3DEP data and tools are crucial for the effective, rapid and actionable interpretation of the resulting information.

Flood Control

Flood-control structures—dams and levee systems—are a major component of the national flood-damage reduction strategy and they represent a major element of American infrastructure. They greatly reduce the frequency of flooding and the extent of flood damage within the basins where they are located and within the constraints of their design. Recent calls for infrastructure renewal will require better understanding of flood hazards and more accurate, quantifiable estimates of flood risks with which to update existing structures and design new ones. USGS streamflow information (https://www.usgs.gov/science/mission-areas/water/groundwater-and-streamflow-information?qt-programs_l2_landing_page=0#qt-programs_l2_landing_page) and flood-magnitude predictive equations as presented in USGS StreamStats (https://water.usgs.gov/osw/streamstats/) need to be improved and extended to provide these estimates. Longer periods of flood records and high-resolution, detailed basin-characteristics data are the primary drivers of such improvements. Where they are available, 3DEP

data already comprise important source inputs for more accurate equations. For this reason, increasing the availability of 3DEP data could lead to major improvements in the estimating of floods and associated flood risks, and in the design and renewal of flood-control structures and the hundreds of thousands of miles of storm sewers and culverts that are needed to convey floodwaters away from inhabited areas.

Flood Forecasting

The second major element of the national flood-damage reduction strategy is improved flood forecasting. Historically, the National Weather Service (NWS) has provided flood forecasts for some 4,000 locations based on NWS rainfall-runoff models driven by NWS rainfall forecasts and USGS streamflow data. But the forecasts typically feature predictions of the magnitude and timing of flood flows, which are difficult for most citizens and many emergency managers to understand and use effectively. Fortunately, the USGS and the NWS have developed flood-inundation map tools (https://water.usgs.gov/osw/flood_inundation/) (U.S. Geological Survey, 2016) that convert such information into understandable, actionable maps that describe the evolving extent of a flood, hour-by-hour, street-by-street, and house-by-house. All of this work, however, requires highly detailed terrain and structure location data of the nature and quality that only lidar technologies can provide and for which 3DEP is ideally suited (fig. 2). The National Water Model by the NWS greatly scales-up the benefits of flood-inundation mapping; the model uses data from more than 8,100 USGS streamgages and forecasts flood flows for some 2.7 million stream reaches of the National Hydrography Dataset Plus. A substantial and sustained national rollout of flood-inundation mapping powered by 3DEP and coupled with the National Water Model could lead to better and more impactful flood-forecasting throughout the Nation, at substantial savings.

Flood Insurance

The third major element of the national flood-damage reduction strategy is the FEMA National Flood Insurance Program (NFIP). In exchange for
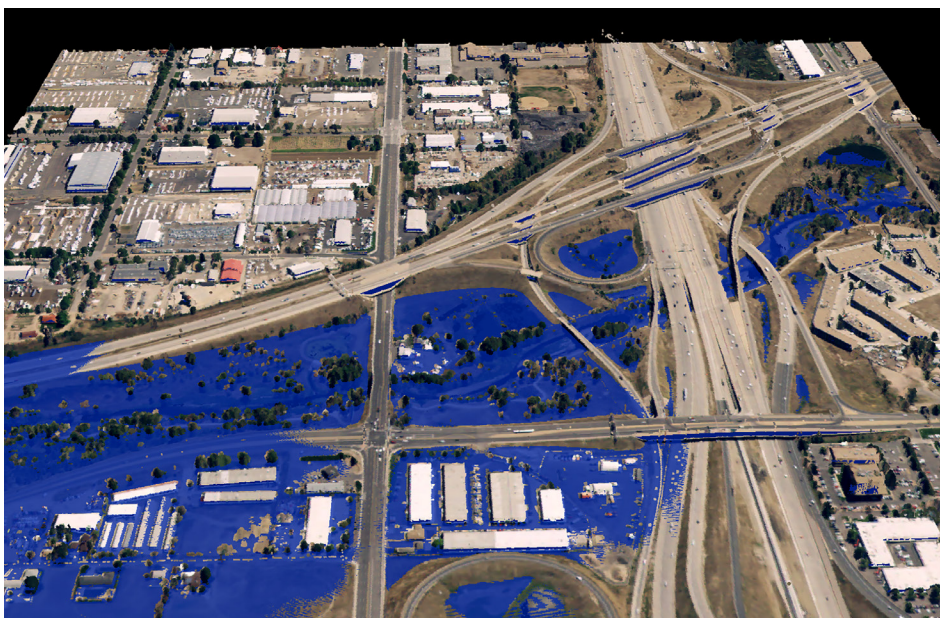

Figure 2. A 3D Elevation Program lidar point cloud colored by RGB color from imagery from the National Agriculture Imagery Program and showing simulated flooding (in blue) of an area in Denver, Colorado. Image courtesy of Jason M. Stoker, U.S. Geological Survey.
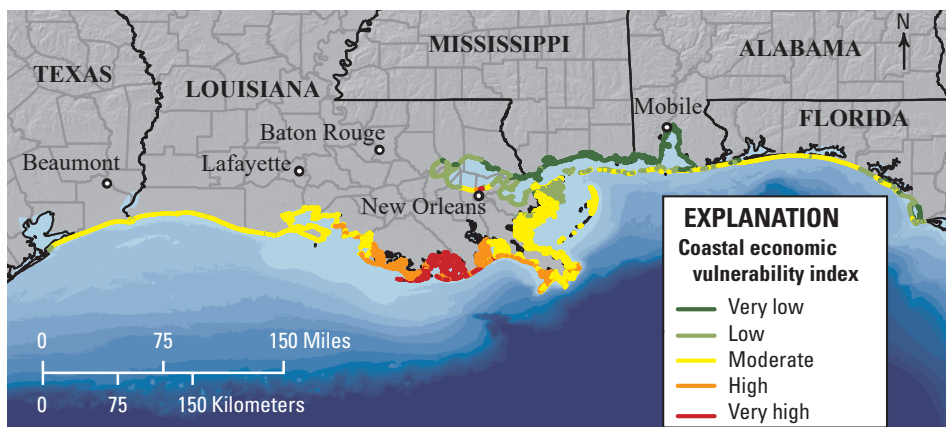
Figure 3. Example of a flood-risk product that is enhanced with lidar information. The vulnerability of human populations and infrastructure to projected increases in sea level can be delineated when lidar-derived, high-quality digital elevation models are available for use in the analysis. Modified from Thatcher and others (2013).

communities adopting and enforcing flood-plain land-use regulations and developmental restrictions designed to limit future flood damage, community residents are given the option to purchase NFIP-sponsored flood insurance. However, traditional NFIP Flood Insurance Rate Maps (FIRMs) identify the flood plain as the area encompassing the extent of the 1-percent-chance flood (as determined through analysis of USGS flood data and StreamStats equations or rainfall-runoff model studies). Almost all of the properties within the flood plain are charged for insurance at rates that are more or less the same regardless of the actual flood risk to which a property is exposed, including the most risky subset of properties that have been repeatedly damaged by floods only to be rebuilt. In response, FEMA developed the RiskMAP program to usher in a series of administrative and technical reforms to improve program performance.

Congress, through the Biggert-Waters Flood Insurance Reform Act of 2012 (Public Law 112-141, 6 July 2012, 125 Stat. 916), codified many of the Risk-MAP reforms, re-established the FEMA Technical Mapping Advisory Council (TMAC) (FEMA, 2014), and charged FEMA with improving the flood insurance process and increasing the accuracy and reliability of flood-plain maps. The TMAC has offered numerous recommendations for program improvement. The two most important are (1) for FEMA to transform flood-plain mapping into a digital process and (2) to base flood insurance premiums on structure-specific

(that is, individual houses and buildings) flood risk. Both recommendations are formulated around the anticipated widespread availability and use of 3DEP data and products. Coupled with other TMAC recommendations and FEMA initiatives, these recommendations could revolutionize the flood insurance process and induce flood-threatened communities and individuals alike to take urgently needed, damage-mitigating actions.

Assessing, Documenting, and Communicating Flood Risk Information

High-quality elevation data, like that collected through 3DEP, are invaluable for assessing and documenting flood risk and communicating detailed information to both responders and planners alike (fig. 3). Multiple flood-mapping programs make use of USGS streamflow and 3DEP data (fig. 4). Flood insurance rate maps, flood documentation studies, and flood-inundation map libraries are products of these programs.

Flood Insurance Rate Maps—FEMA's flood hazard mapping program, RiskMAP, identifies flood hazards, assesses flood risks, and partners with States and communities to take actions that reduce flood risk. Flood hazard mapping is an important part of the NFIP, as it is the basis of that program's flood-plain management and flood insurance requirements. FEMA maintains and updates data through FIRMs and risk assessments. FIRMs include statistical information such as data for river flow, storm tides,

hydrologic and hydraulic analyses, and rainfall and topographic surveys.

Flood documentation studies—Flood documentation studies, typically containing maps, record the extent of a particular flood event to support where immediate flood response should be focused. They also inform where future flood-plain planning is needed and evaluate the need for future more detailed flood-plain study, and they can be used to support flood insurance claims.

Flood-inundation map libraries—Flood-inundation maps that are tied to USGS real-time streamgage data and to NWS flood forecasts enable officials to make operational and public-safety decisions hours, or even days, prior to flooding and during the event on a street-by-street, block-by-block basis. A library is a series of consecutive maps showing the extent of flooding at increasing flood elevations, typically created at one-foot to two-foot stream stage intervals.

Examples of Federal, State, and local collaboration

The following are examples of Federal, State, and local collaboration in assessing, documenting, and communicating flood risk information associated with damage from floods and hurricanes.

Figure 4. The Coleman Bridge spanning the York River between Gloucester Point and Yorktown, Virginia. In this view at Gloucester Point, floodwater covers a park and parking lot in the foreground, and in the distance waves can be seen breaking over the riverbank. USGS 3DEP and streamflow data help with mapping and increasing awareness of floods like these. Photograph courtesy of Virginia Institute of Marine Science.

Flood Insurance Rate Maps—North Carolina began collecting lidar data in 2000 that allowed the State to increase the number of flood studies with minimal program cost impacts. This allowed the completion of flood maps that depicted the special flood-hazard areas defined as the 100- and 500-year flood hazard zones for North Carolina. From 2000 to 2008 the flood-plain mapping program conducted hydrologic and hydraulic studies on nearly 27,000 miles of streams, rivers, and coastline. From these studies the State has established 305,530 base flood elevations and generated 8,609 FIRMs.

In 2014, North Carolina began collecting higher quality (quality level 2; see 3D Elevation Program sidebar) lidar data to further modernize the flood mapping program and to move from hazard identification to risk assessment and identification. With the introduction of the new digital flood maps it is possible to determine flooding risk for individual structures (fig. 5) (see http://fris.nc.gov/fris) (North Carolina Floodplain Mapping Program [2016?]). The goal is for the population to understand the impact of floods at their location. The high-quality surface terrain shown on the maps allows citizens to make wise decisions about their homes, their savings, and their future.

Hurricane Sandy flood documentation map—In late October 2012, Hurricane Sandy blew ashore in New Jersey, causing record flooding there and in New York (fig. 6) and elsewhere in the Northeast. Immediately following the storm, USGS crews collected high-water-mark data that were combined with high-resolution lidar data (McCallum and others, 2013). The resulting high-quality flood documentation maps allowed FEMA to quickly ascertain damage levels to specific homes and disburse immediately needed funds much faster than ever before. This event demonstrated the enormous and unique value of post-flood documentation maps. The USGS and FEMA have continued to develop and use this kind of map in subsequent major inland and coastal floods, including the August 2016 flood in Baton Rouge, Louisiana.

Saline River flood-inundation map—The Saline River is a tributary to the Ohio River in southern Illinois that, until a few years ago, had a very large flood problem and no available lidar data. The USGS initially completed a pilot flood-inundation map library with 30-meter-resolution elevation data. The maps were rough, but detailed enough to show the community which areas were at risk. In fact, the maps were so useful that the community acquired lidar data the next year and the USGS recomputed all the mapping to a much higher, 10-meter resolution (Murphy and others, 2012). The higher resolution maps are allowing the community to plan for and respond more effectively to floods.

Benefits of 3D Elevation Data

The benefits that can be realized by flood hazards mapping agencies and the industries that depend on this information are significant. Improved elevation data, in part, leads to improved flood risk products, which enables more informed

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According to the National Academy of Public Administration study completed for FEMA's flood mapping program (National Academy of Public Administration, 2013)—

"The 3DEP plan for a jointly funded program to collect elevation data systematically on a nationwide basis offers a significantly more cost-effective alternative to current piecemeal efforts, and will benefit not only FEMA's flood mapping efforts but also users across the Federal government, as well as States and localities." —Finding 4d (p. 82).

"The 3DEP plan represents an extraordinary interagency effort to develop a mechanism for more efficiently funding the collection of a key input to more accurate flood mapping as well as other important Federal, State, and local mapping activities." —Discussion on p. 83.

"The Office of Management and Budget should use the 3DEP implementation plan for nationwide elevation data collection to guide the development of the President's annual budget request." —Recommendation 15 (p. 87).
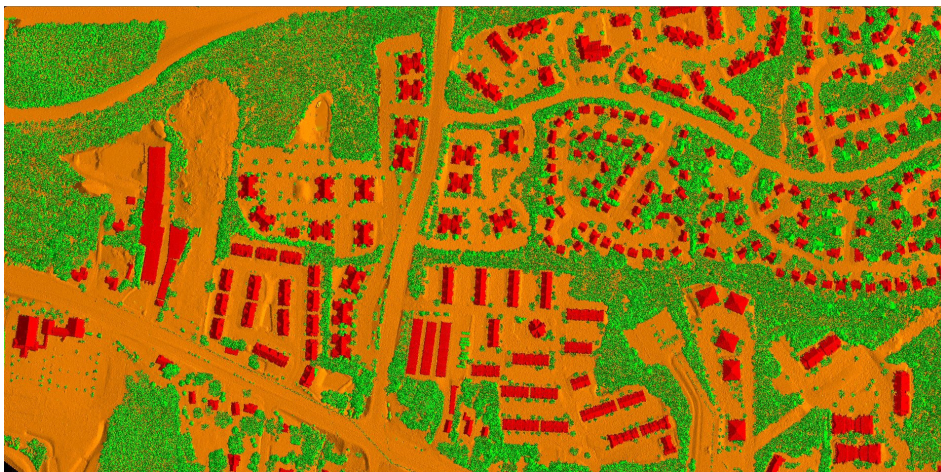

3D Elevation Program (3DEP)

The 3D Elevation Program (3DEP) is a program managed by the USGS to acquire high-resolution elevation data for the Nation (Sugarbaker and others, 2014). It produces point clouds, bare-earth digital elevation models (DEMs), and other products.

3DEP is backed by a comprehensive assessment of light detection and ranging (lidar), interferometric synthetic aperture radar (IfSAR), and related elevation data requirements (Dewberry, 2012). The goal of this high-priority cooperative program is to acquire complete coverage of quality level 2 lidar data for the conterminous United States, Hawaii, and the U.S. territories, and IfSAR data for Alaska, by the end of 2023.

Reduced Acquisition Costs and Risks

A funded national program will provide the following:

- *Economy of scale* by acquiring data for larger areas and reducing acquisition costs by 25 percent.

- *Predictable, efficient, and flexible Federal investments* that reduce costs for and allow better planning by Federal, State, Tribal, U.S. territorial, and local government partners, including the option of "buying up" to acquire higher quality data.

- *Consistent, high-quality national coverage* that (1) provides data ready for applications that span project, jurisdictional, and watershed boundaries, (2) meets multiple needs, and (3) increases benefits to citizens.

- *Simpler data acquisition* that provides contracts, published data-acquisition specifications, and specialized quality assurance and information technology expertise. Partners reduce their risks and can concentrate on their business activities.

3DEP can conservatively provide new benefits of $690 million per year and has the potential to generate $13 billion per year in new benefits through applications that span the economy (Dewberry, 2012).

Figure 5. Lidar data can be used to extract building footprints (in red) and identify the finished floor elevation in order to quantify potential damage based on flooding depths and to determine if buildings are above the base flood elevation. Image courtesy of John Dorman, North Carolina Floodplain Mapping Program.

regulatory and development decisions and potential reduction in property losses. State, Federal, and local agencies that participated in the National Enhanced Elevation Assessment study (Dewberry, 2012) conservatively identified $295 million in new annual benefits attributable to improved elevation data for supporting flood hazard mapping. Most of these benefits are associated with the reduction of property losses.

Maximized Benefits and Minimized Risks

3DEP presents opportunities for users to maximize the benefits and minimize the risks associated with collecting and analyzing mapping terrain data for their project. Data that meet the needs of the user's project may already be available through 3DEP. As such, users may benefit by taking advantage of previously derived product data, or the standardized point cloud, to ease or avoid the learning curve associated with processing raw lidar data. The user can then begin project work immediately.

When new data must be acquired, 3DEP offers:

- Reduced unit collection costs through the possibility of pooled funding with other partners and the economy of scale that 3DEP acquisition provides.

- Access to qualified and experienced firms under contract that acquire and process aerial lidar data.

- Programmatic infrastructure that issues and manages data acquisition contracts, and inspects, accepts, and distributes point cloud and derived data products.

- Opportunity to "buy up" higher quality data for specialized applications.

- Opportunity to receive 3DEP cost-share funding to acquire lidar data.

Figure 6. Hurricane Sandy devastated Long Island and other coastal areas of New York in late October 2012. To effectively assist with recovery efforts, the Governor created the New York Rising Community Reconstruction Program, which recognizes lidar data as a critical resource to better manage the impacts of catastrophic weather events. Photograph courtesy of New York State Information Technology Services, Geospatial Information Systems Program Office.

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3D Elevation Program (3DEP)—Continued

Data are available, free of charge and without use restrictions. To download 3DEP products visit http://viewer.nationalmap.gov/basic/.

Ways to Participate

Partners may contribute funds toward data acquisition projects managed by the USGS, or they may receive cooperative funds to manage their own acquisition projects. The Broad Agency Announcement process is the primary mechanism used to establish agreements between partners. For more information see the 3DEP website at http://nationalmap.gov/3DEP/index.html. Organizations may also access the geospatial products and services contracts and quality-control services managed by the USGS to acquire 3DEP data. Organizations may contribute existing elevation data that meet 3DEP specifications. More information about using USGS contracts or about other ways to contribute is available by request through http://nationalmap.gov/3DEP/3dep_feedback.html

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Learn More about 3DEP

See the websites in the 3D Elevation Program sidebar. Please send questions to:

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Or visit the National Geospatial Program website at https://www2.usgs.gov/ngpo/