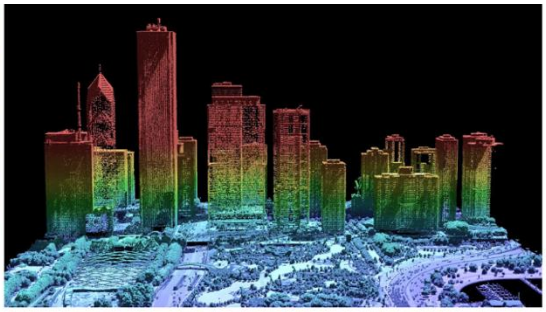
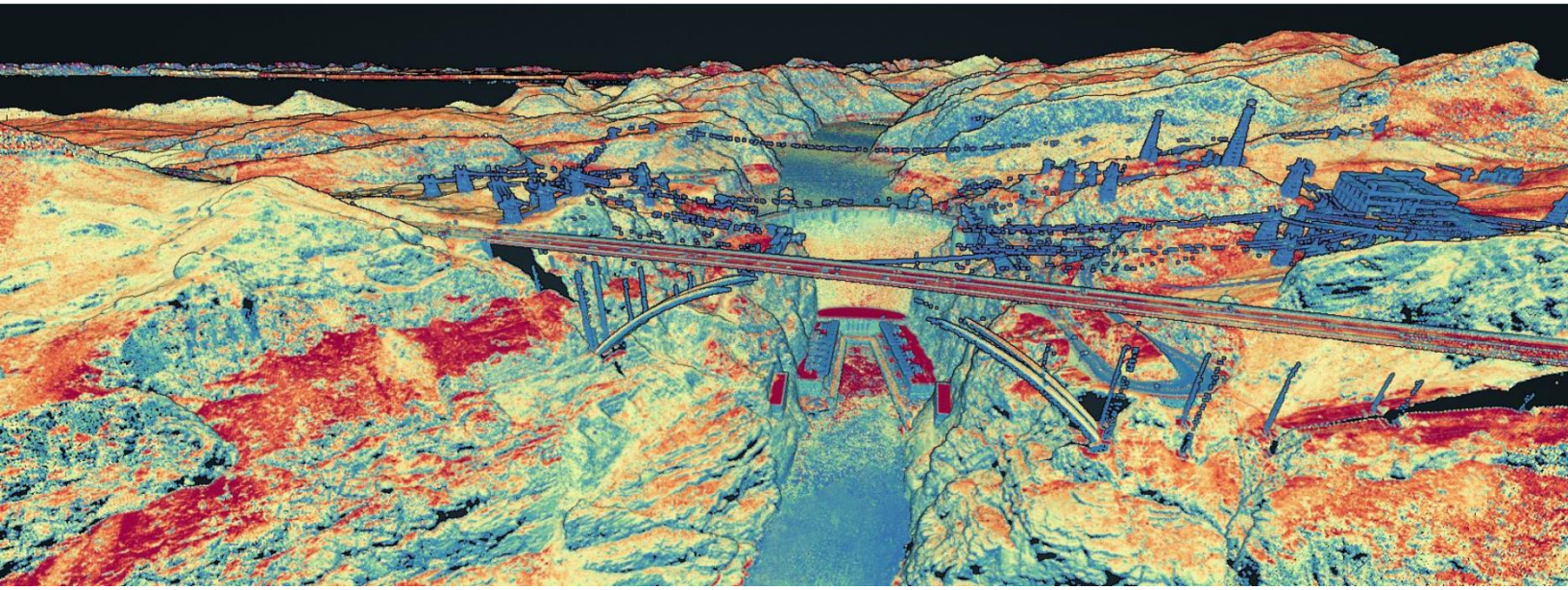
Assessment of the 3D Elevation Program



National Geospatial Advisory Committee
3D Elevation Program Subcommittee
June 2023

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FEDERAL GEOGRAPHIC DATA COMMITTEE

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EXECUTIVE SUMMARY

NGAC 3DEP SUBCOMMITTEE TASK

The National Geospatial Advisory Committee (NGAC) 3D Elevation Program (3DEP) Subcommittee was established through the National Landslide Preparedness Act (NLPA), P.L. 116-323. The Federal Geographic Data Committee (FGDC) coordinated with the Department of the Interior's United States Geological Survey (USGS) to establish the subcommittee and appoint members.

The NLPA directs the subcommittee to assess the 3DEP program on the following topics:

- Trends and developments in the collection, dissemination, and use of three-dimensional (3D) elevation data
- The science and technology relating to 3D elevation data
- The effectiveness of 3DEP in carrying out the activities as described in the Act.
- The need to revise or reorganize 3DEP
- The management, coordination, implementation, and activities of 3DEP

The 3DEP Subcommittee is comprised of geospatial community experts from within the NGAC membership and from across State and local government units, academia and research institutions, standards development organizations, and the private sector.

SUMMARY OF THE 3DEP SUBCOMMITTEE ASSESSMENT

The 3D Elevation Program

Managed by the U.S. Geological Survey (USGS), in coordination with numerous partner agencies, 3DEP provides high-quality, high-value data that is widely used by government and business/industry to inform critical decisions made across our Nation every day that depend on elevation data, ranging from immediate safety of life, property, and environment to long-term planning for infrastructure projects. Improving hydrologic forecasting models and flood-risk maps with reliable elevation information has a positive impact on preparation for natural disasters. Understanding elevation data assists in the management of critical infrastructure, detecting land-surface changes from natural processes, such as landslides and erosion, and from human activities like urban growth and precision agriculture.

The goal of 3DEP is to acquire nationwide lidar (interferometric synthetic aperture radar (IfSAR) in Alaska), to provide the first-ever national baseline of consistent, high-resolution topographic elevation data, both bare earth and 3D point clouds. The first full year of multi-year 3DEP production was initiated in 2016 to respond to growing needs for high-quality topographic data and a wide range of 3D representations of the Nation's natural and constructed features. The program is based on a National Enhanced Elevation Assessment (NEEA), published in 2012, that identified over 600 requirements for high-resolution 3D elevation data to address critical mission needs of 34 Federal agencies, 50 States and two territories, selected local and Tribal governments, and private-sector and not-for-profit organizations. A multi-year, nationwide

community partnership has been instrumental in funding 3DEP, with significant investments coming from other Federal and non-Federal partners to augment USGS investments.

This report underscores significant opportunities to build upon what has already been accomplished, notes how continuous improvement advances a promising future, and offers recommendations which should be considered to reinforce the successes of the current program and, where appropriate, to redesign the program to flexibly integrate and share more data sources.

Trends and developments in the collection, dissemination, and use of 3D elevation data

As of the end of FY22, elevation data for approximately 89.5% of the Nation was available or in progress. Operating on an annual budget of ~$36M, the program has been recognized as a resounding success throughout the geospatial data-using community. Moreover, the program has attracted and managed partner funding and leveraged the power of the private sector to provide efficient data acquisition and processing services. About 65% of the cost of 3DEP has been contributed by over 300 partners for data acquisition, the majority of which come from the public sector. Nationally, 3DEP has generated an estimated return on investment of 5:1, with benefits estimated to be ~$690 million per annum with potential to increase to $1 billion if fully funded for completion within 8 years.

Standardized and authoritative 3DEP data is available free of license or restricted use through The National Map. This democratization of data has enabled users to download 3DEP data, access it, work with it, and transform it into geo-information to make informed decisions. Public and private entities can apply their analytics for their own benefit. 3DEP, in a way, is a geo-data public utility. Overall, 3DEP has paved a path for a rich consumer experience. Availability, accessibility, and distribution mechanisms continue to advance vigorous data dissemination developments.

Lidar has been the technology of choice for 3DEP (IfSAR in Alaska). Over the last few decades, gains in data-capture productivity, speed and precision have been transformative for the broader surveying and mapping applications. Developments in artificial intelligence/machine learning (AI/ML), electronics miniaturization, and signal processing have all contributed to improvements in lidar. Related enabling technologies such as the Global Navigation Satellite System (GNSS), inertial measurement units (IMUs), camera systems, data processing, and validation methods have also had significant gains.

3DEP has advanced relevant standards - of which the Lidar Base Specification[1] (LBS) is the best known - best practices, and effective governance, in ways that help optimize current acquisition, data management and distribution. A broad commitment to standards compliance will be essential as more information and services from a diversity of sources become available to address national and international needs across expanding producer and user communities.

The Subcommittee has concluded that 3DEP has successfully advanced toward its initial goal of full high-accuracy elevation coverage of the Nation, helping to address many of the requirements and benefits as described in the NEAA and later expanded upon in the *3D Nation*

[1] https://www.usgs.gov/ngp-standards-and-specifications/lidar-base-specification-online

Elevation Requirements and Benefits Study[2] (referred to hereafter as the "3D Nation Study"), including U.S. topographic and inland, nearshore, and offshore bathymetric 3D elevation data requirements and benefits. The 3DEP data acquisition model and its effective use have established standard process protocols, including methods that encourage the program to continuously adapt to technological and service improvements.

The management, coordination, implementation, and expanded activities of 3DEP

3DEP is effectively coordinating with other sectors, including State, Tribal and local governments, regional and local agencies, NGOs, and the private sector. This coordination results in boosting 3DEP program investments, information sharing, and messaging regarding the benefits of the program and enhancement of outcomes in communities. One factor in ensuring the success of this coordination is having a partner organization that is knowledgeable about the 3DEP program, who can convene multiple local and regional entities, determine their needs and willingness to provide financial and other investments, and help the coalition to apply for funding under the program. The comprehensive management and governance approach already established for the program and its array of collaborative partners from public and private sectors has been a model for the Nation.

The wisdom to revise 3DEP for the future

The establishment and working cooperation of the NLPA-mandated Federal Interagency Coordinating Committee (FICC) will continue to strengthen the plans for the next generation of 3DEP, part of the 3D National Topography Model (3DNTM) which also includes the 3D Hydrography Program (3DHP). The FICC would provide Federal leadership to achieve the 3DNTM objective of a joint USGS and NOAA 3D Nation vision to provide a continuous elevation surface from the depths of waters to the peaks of mountains.

An envisioned 3DEP Ecosystem concept would govern and connect elevation resources owned and managed by multiple agencies under a single user interface, transforming the program from managing data to providing information. In addition to authoritative 3DEP data managed by the USGS, the 3DEP Ecosystem would provide a standardized method of cataloging and accessing a wide variety of non-authoritative data sets, to enable fit-for-purpose dataset use.

3DEP has been and will continue to be a catalyst for growth of the lidar services and equipment industry, including technology and software tools for capturing, storing, and processing lidar data, and tools for and approaches to generating lidar-derived products and analytics.

3DEP SUBCOMMITTEE RECOMMENDATIONS

Overarching Recommendations

1. First and foremost, the subcommittee recommends that 3DEP "stay the course" to prioritize achievement of 100% national coverage as soon as practical.

[2] https://iocm.noaa.gov/planning/3DNationStudy.html. The study was sponsored by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey and was completed in September 2022. Questions regarding the report should be directed to NOAA and iwg-ocm.staff@noaa.gov. The report was developed by Dewberry under contract to NOAA.

2. The subcommittee recognizes that the USGS is not yet budgeted to address several of the recommendations provided below. However, given the significant projected return on investment discussed in this document, USGS should incorporate these recommendations into its design plans when additional funding is provided to achieve its future vision.

In addition, the subcommittee provides the following recommendations that may help both the planning process and the execution of the resulting programs:

Technical/Technology

3. USGS should collaborate with its contractors to identify elements of the validation process that can be performed by the contractors prior to delivery to USGS validation, in order to speed up the process and help reduce the current 18-24 month delivery timeline. Furthermore, USGS should encourage research on the automation of processes such as qualify control (QC) of 3D point-cloud data.
4. The way work is performed and the expectations of the end-users are constantly changing. USGS and its Geospatial Products and Services Contracts (GPSC) contractors should continue their existing practice of being up-to-date on the latest technologies and products available for lidar data collection and processing. 3DNTM managers should remain open to new products to meet user needs.
5. USGS should leverage new and emerging processing standards and artificial intelligence/machine learning (AI/ML) techniques to streamline and future-proof 3DEP processing, e.g., OGC API-Processes, OGC API-EDR (Environmental Data Retrieval), OGC API-Discrete Global Grid Systems (DGGS).
6. USGS should consider participating in software development sprints to directly engage the technology development and user communities in testing, prototyping, and validating next-generation 3DEP capabilities.

Partnerships

7. USGS should further leverage The National Map Liaison network to increase local and regional participation by exploring opportunities for partner organizations to act as “conveners” or “coordinators” across the country.
8. USGS has communicated widely and effectively on its activities and on the 3DEP program, but the need remains for further education. The Federal Interagency Coordinating Committee (FICC) and USGS should continue to apply effort to directly relate the utility of 3DEP data to key national priorities such as: the Nation’s Infrastructure, climate resilience; planning for, mitigation of and response to disasters; and the management, distribution, and infrastructure of water.
9. The NGAC 3DEP Subcommittee understands that Congress has recognized the connection lidar and USGS 3DEP provide for the national broadband mapping efforts. To reduce the digital divide, all Federal agencies involved in broadband mapping, coverage, and the deployment of related infrastructure-- such as the Federal Communications Commission (FCC), National Telecommunications and Information Administration

(NTIA), and Rural Utilities Services (RUS), among others—should fully leverage, participate, partner, and help to fund the 3DEP.

10. While USGS has been successful in partnership building, extensive efforts to reach out to key industry segments such as infrastructure and transportation, agriculture, and broadband and telecom, have not resulted in significant funding partnerships. USGS should continue to investigate and pursue private sector investment approaches that could help enable the goals of next generation 3DEP program.

Program Enhancement/Future Plans

11. USGS and partners should embrace and implement the 3DEP Ecosystem concept as described in this report. That would allow for the import and integration of local acquisitions from agencies such as State Departments of Transportation (DOTs) with their statewide elevation data sets. The Ecosystem could provide a central location where users can find some level of authoritative data and share useful data that might not meet all the 3DEP specifications but supplies the quality and "fit for use" assessments provided by data producers. Data analysis tools and code could also be shared.
12. 3DEP data storage and dissemination are extremely important, especially as change detection from multiple collections over time becomes increasingly needed and should be fully funded.
13. 3DEP should fully document the 3DEP system architecture to identify key system components, processes, standards, and data formats necessary to ensure interoperability across partners and the broader community, and to enable more effective and efficient 3DEP evolution.
14. 3DEP should include a requirement to develop a seamless 1-meter digital elevation model (DEM) for derivation of hydrography from elevation data.
15. 3DEP should explore workflows and processes that may yield Analysis Ready Data (ARD) and Decision Ready Information (DRI) of value to the community based on key indicators.

Standards

16. 3DEP should explore increasing representation and resources in relevant Standards Development Organizations (SDOs) such as those described in this report. Current levels of shared expertise and collaborative support are insufficient to properly influence standards development activities that support 3DEP operations and evolution.

Governance

17. USGS should implement the design for the next generation of 3DEP described in the 3D National Topography Model Call for Action Part 2: Next Generation 3D Elevation Program ("the 3DNTM draft plan") due for publication by USGS later this year.

18. The Department of the Interior in coordination with the Departments of Commerce and Homeland Security and with the support of USGS should fully implement the governance process outlined in the NLPA.
19. FICC and FGDC leadership should ensure participation from a broad range of Federal agencies with a need for data delivered through the 3DEP program.

CONCLUDING COMMENTS

The Subcommittee has concluded through this assessment that 3DEP has successfully advanced its initial goal of full lidar coverage of the Nation, helping to address many of the requirements and benefits as described in the NEEA. The comprehensive management approach already established for the program and its array of partners from all national sectors has been a model for the Nation, which will only be enhanced through the establishment of an Interagency Coordinating Committee as directed by the NLPA.

There is opportunity for further, substantial improvement in 3DEP quality, efficiencies, and capabilities to support a growing range of user needs, given additional partner or appropriated funding. The vision for the next generation of 3DEP will build a modern elevation foundation for stronger, more resilient communities that strengthen and expand the U.S. economy, improve environmental and ecological decision-making, and ensure effective and efficient communication and transportation infrastructures.

The very successful public/private partnerships, established by the 3DEP and nourished by the USGS managers, should continue, with added vigor, in the next generation.

INTRODUCTION

3DEP provides high quality, high-value data that is widely used by government and business/industry to meet a broad range of needs, based on knowing more about the Earth's topography. 3DEP data acquisition and use have become an industry standard as the program continuously adapts to technological improvements. USGS manages the program with numerous partner agencies within its existing authority.

The goal of 3DEP is to acquire nationwide lidar[3] collections (IfSAR in Alaska) to provide the first-ever national baseline of consistent, high-resolution topographic elevation data, both 3D point clouds (delineating features on the surface such as trees, buildings) and bare earth (lidar processed to remove features, resulting in a digital elevation model). A multi-year 3DEP, managed by the USGS National Geospatial Program (NGP), was envisioned in *The 3D Elevation Program Initiative – A Call for Action*[4] (2014) to respond to growing needs for high-quality topographic data and a wide range of 3D representations of the Nation's natural and constructed features. The program is based on the NEEA that identified over 600 requirements for high-resolution 3D elevation data to address critical mission needs of over 34 Federal agencies, 50 States, Tribal governments, and private-sector organizations. A multi-year, nationwide community partnership has been instrumental in funding 3DEP, with significant investments coming from other Federal and non-Federal partners to augment USGS investments[5].

As of the end of FY22, data for approximately 89.5% of the Nation is available or in progress (Figure 1). 3DEP focuses on the collection of high-resolution 3D elevation data; facilitating the coordination, sharing, and use of this data across Federal and non-Federal, public, and private entities to produce publicly accessible data products for the U.S.; and promotion of 3D elevation data collection, dissemination, and use across all levels of government, institutions of higher education, and the private sector. 3DEP products and services are available through The National Map.[6] They include point clouds and DEMs at various horizontal resolutions. All 3DEP products are available free of charge and without use restrictions.[7]

Given the approximately 90% nationwide coverage already available or in progress at the end of FY22, the program has been recognized as a resounding success. With an average annual budget of ~$36 million, the program has attracted and managed partner funding and has

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[3] Alaska is the exception. The USGS coordinated with other Federal agency partners and the State of Alaska to fund the acquisition of the Alaska Interferometric Synthetic Aperture Radar (IfSAR) data from 2010 to 2019.

[4] Sugarbaker, L.J., Constance, E.W., Heidemann, H.K., Jason, A.L., Lukas, V., Saghy, D.L., and Stoker, J.M., 2014, *The 3D Elevation Program initiative —A call for action: U.S. Geological Survey Circular 1399*, 35 pp, *http://dx.doi.org/10.3133/cir1399*.

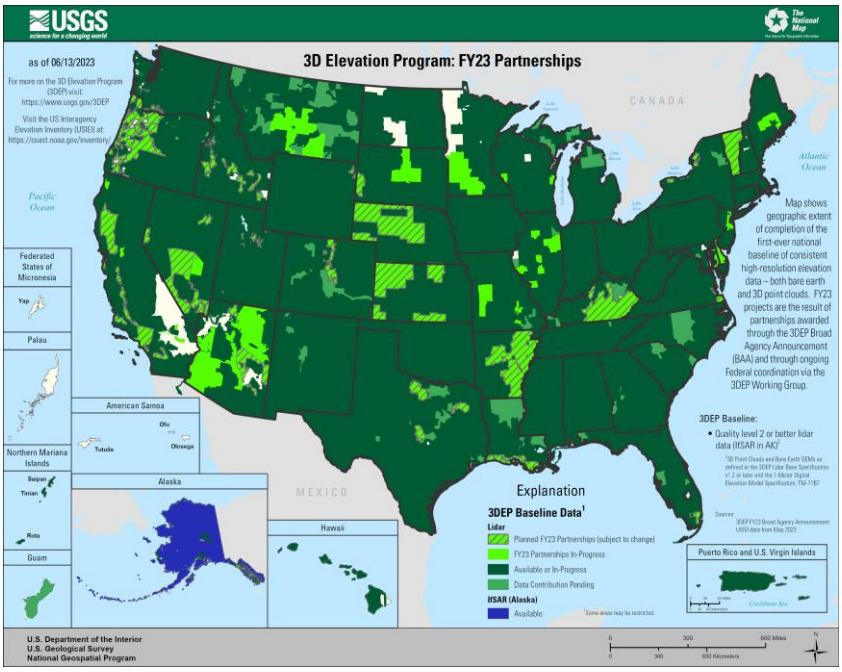
[5] 3DEP By The Numbers | U.S. Geological Survey (usgs.gov), www.usgs.gov/3d-elevation-program/3dep-numbers

[6] https://www.usgs.gov/programs/national-geospatial-program/national-map

[7] https://www.usgs.gov/3d-elevation-program/about-3dep-products-services

leveraged the power of the private sector to provide efficient data acquisition and processing services. About 65% of the cost of 3DEP for data acquisition has been contributed by over 300 partners, the majority of which are from the public sector. 3DEP was designed based on the NEEA to produce an estimated return on investment of 5:1, with annual benefits estimated at ~$690 million with potential to increase to $1 billion[8] if fully funded for completion in 8 years.

Moreover, the program has advanced relevant standards - of which the LBS is the best known - best practices, and effective governance, in ways that will benefit future developments. Future applications of interoperable data, information, and services from a diversity of sources, will



As of FY22 89.5% of the Nation had 3DEP data available or in progress (shown in dark green and blue). New acquisitions planned for FY23, as of 13 June 2023, are shown in bright green.

Figure 1. Map of 3DEP data availability. Latest status available at www.usgs.gov/media/images/3d-elevation-program-fy23-partnerships

rely upon reliable commitment to standards compliance when addressing national and international needs across expanding producer and user communities.

The significance of 3DEP to the Nation has drawn the attention of Congress. In 2021 the NLPA established a 3DEP Subcommittee under the NGAC. The NGAC is a Department of Interior (DOI) Federal Advisory Committee, which provides advice and recommendations to the FGDC on national geospatial policy issues. The 3DEP Subcommittee is comprised of appointed experts from within the NGAC membership and from across State and local government units,

[8] Data from a USGS internal paper, "3D Elevation Program – USGS NDP Summary of Successes and Challenges," drawn from 3D Elevation Program Fiscal Year 2015 - 2022 Expenditures | U.S. Geological Survey (usgs.gov)

academia and research institutions, standards development organizations, and the private sector (see Appendix 1). The subcommittee's task is to conduct an assessment of the:

- Trends and developments in the collection, dissemination, and use of 3D elevation data and in science and technology relating to 3D elevation data.
- Effectiveness of 3DEP in conducting the activities described in the Act.
- Need to revise or reorganize 3DEP.
- Management, coordination, implementation, and activities of 3DEP.

The subcommittee was directed by the Act to produce a report within one year of its establishment. In response, this report details the findings of the assessment as assigned above, and makes several recommendations based on those findings. To focus its work, the subcommittee organized itself into two work groups: a Trends and Developments Work Group and a Program Management Work Group. Findings and recommendations from these work groups have been consolidated to produce this first-year report.

This report underscores significant opportunities to build upon what has already been accomplished, notes how continuous improvement advances a promising future, and offers recommendations which should be considered to enhance the program design for improved flexibility, efficiency, and capability. Recommendations included in this report accommodate developments in technology, leverage an improved understanding of user needs, and address emerging applications.

As the 3DEP Subcommittee conducted its assessment, working group members realized that the assessment of "science and technology, relating to 3D elevation data" as called out in the subcommittee task was embedded within the other specifically identified "trends and developments." Consequently, there is no separate section for science and technology. However, the topic is covered within the sections that follow.

THE NEXT GENERATION OF 3DEP

To assist the subcommittee's assessment of trends and developments with 3DEP and ongoing work for the program's future direction, USGS provided a draft document that outlines the emerging program plan for the next generation of 3DEP. Insights from that plan have contributed to this report. USGS had previously presented the major components of the emerging plan to key partners and stakeholders including the 3DEP and 3DHP Working Groups, National Society of Professional Surveyors (NSPS), MAPPS[9], the National States Geospatial Information Council (NSGIC), and the U.S. Geospatial Executives Organization (US GEO). USGS is revising the proposed plan based on stakeholder feedback with the goal of releasing a final

[9] Formerly known as the Management Association for Private Photogrammetric Surveyors, MAPPS is an association of geospatial private sector firms in the U.S., www.mapps.org

draft document for a broader community review in summer of 2023, with a vetted and finalized program design published in Fiscal Year 2024.

The first generation of 3DEP provides an essential national baseline of consistent, high-quality data that will continuously grow in value as it is used for comparison with new data collected over time. USGS is drawing on the 3D Nation Study, its experience with managing the 3DEP baseline, and stakeholder feedback to design the next generation program. The key features of the next generation of 3DEP being considered at the time of this report include:

- More frequent collections of higher quality nationwide topographic lidar to support existing and new business requirements Development of a 3DEP Ecosystem to govern and connect elevation resources owned and managed by multiple agencies under a single user interface, transforming from managing data to providing information. The 3DEP Ecosystem will enable direct access and use of authoritative 3DEP data managed by USGS. It will also provide a standardized method of cataloging and accessing the wide variety attributes of non-authoritative data sets, to enable fit-for-purpose dataset selection and use.
- A plan to reassess the program design every 5 years to adjust course as needed to meet new partner needs, make use of new technologies, and/or move to a change-based refresh approach that will be researched and developed over the next several years.
- Focused coordination and development of best practices for inland bathymetry over the next 5 years to leverage partner investments and advance towards a more systematic national approach.
- An active research agenda that will provide major input into the 5-year assessment as well as evolving the direction of the program. Research topics include the 3DEP Ecosystem/data mesh, inland bathymetry, change detection to drive program updates, a national tiling system, new sensors, lidar-imagery integration, full 3D accuracy testing, uncertainty reporting, and more.

The proposed program design for the next generation 3DEP would meet approximately 66% of the needs documented in the 3D Nation Study, provide an estimated $7.6 billion in annual benefits, and cost approximately $259 million a year if fully funded. To meet community needs and achieve the benefits of next generation 3DEP, advocacy should begin now for appropriate increases to the 3DEP budget. Refer to Figure 2 for comparison between the baseline and the next generation.

This improved program design is intentionally ambitious yet similar in relative magnitude to the original 3DEP baseline goal in terms of the community-wide involvement and funding increase it requires. It is impossible to predict the degree to which the community requirements documented in the 3D Nation Study will be accomplished until the increased investment in the next generation 3DEP is well-understood. The USGS strategy to manage this uncertainty will be to assess the funding trajectory in year 5 to determine if adjustment is necessary and to address

other changes to the program design to balance and best meet evolving user needs and investments.

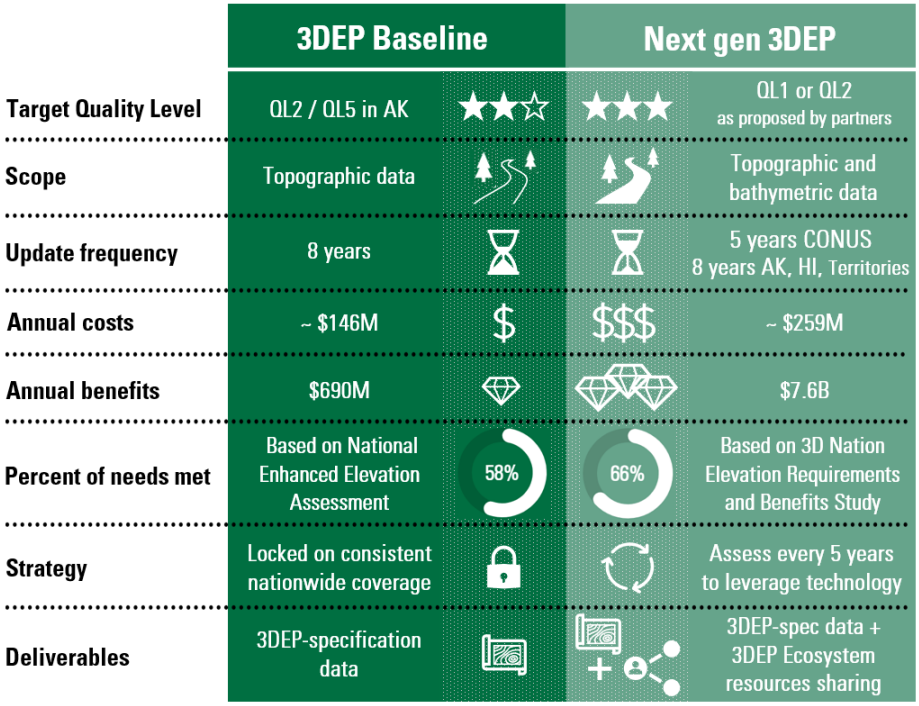


Figure 2. Comparison of 3DEP baseline program goal with proposed next generation 3DEP goal in terms of quality level, scope, update frequency, cost, needs met, strategy, and deliverables subject to change as the final program design is completed.

TRENDS AND DEVELOPMENTS IN 3DEP DATA COLLECTION AND PROCESSING

The nationwide data collection objective has been well established. The approach to specific collections relies upon successful processes. Data collection begins with communication between potential partners (as seen in Figure 3) to define project scope and continues through funding agreements, the contracting process, and the data acquisition, data processing, and quality assurance processes that result in final deliverables. The extraordinary amount of communication and coordination between partners built into this process has been a critical factor in the success of the program.

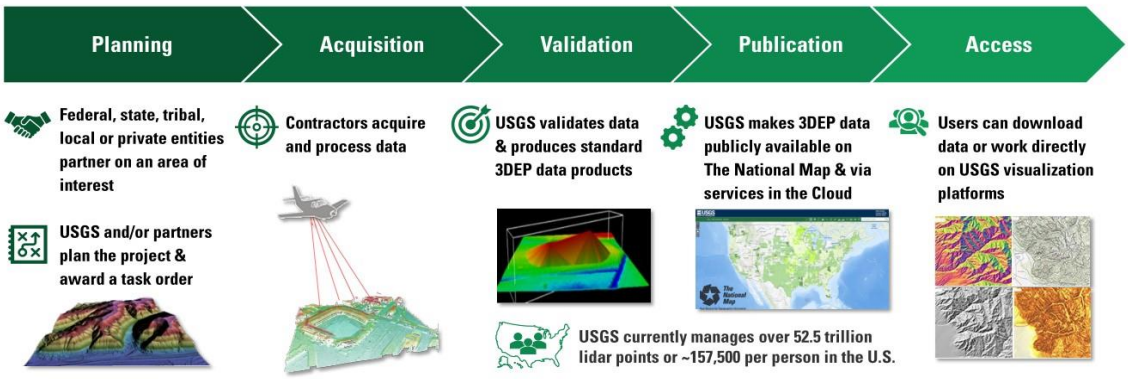


Figure 3. 3DEP high level process / workflow, source: USGS

The 3DEP governance and Broad Agency Announcement (BAA) process[10] have been remarkably effective at bringing partnerships together to achieve larger projects with diverse stakeholders. The role of the private sector in the partnership development process, specifically the Geospatial Products and Services Contracts (GPSC) contractors, encourages greater understanding of and crosscutting relationships with State and local partners while conducting their regular business. (More about this process is described below.) These partnerships have had a significant impact on fostering collaboration among stakeholders. This model public-private partnership is a beacon for all other Federal agencies and has raised the bar for program management quality and cost-effectiveness.

The NGP developed LBS has brought order and standardization to the myriad of Federal agencies' data acquisition requirements and is the foundation upon which the effectiveness of the data acquisition is built. LBS has been updated seven times since its initial publication in 2012, illustrating the USGS commitment to keeping up with rapid technological change and evolving agency requirements. It is a model that has been referenced and applied by other domestic and international programs.

Data Collection Technologies

As noted above, lidar has been the technology of choice for 3DEP (IfSAR in Alaska). Over the last few decades, the growth and development of photonics, lidar, and SAR have been dramatic, producing tremendous improvements in the efficiency, speed, precision, and accuracy of acquired data. The resulting gains in data-capture productivity have been transformative for broader surveying and mapping applications. Advancements in AI/ML, electronics miniaturization, and signal processing have all contributed to improvements in lidar. Related enabling technologies such as the GNSS, IMUs, camera sensor and platform systems, data

[10] https://www.usgs.gov/3d-elevation-program/3dep-broad-agency-announcement-portal

processing, and validation methods have also experienced significant gains. Described below are data collection technologies that have been used and are being considered for 3DEP:

- Linear-mode lidar systems have been the predominant technology for 3DEP CONUS data acquisition. These systems offer effective measurement speed, very high accuracy and precision, and the lowest false-alarm rate of the data. Linear-mode lidar systems include purpose-built scanning mechanisms to enhance complex data capture of the built and natural world. These systems are readily available from multiple suppliers and substantial numbers are in use throughout the world.
- Geiger-mode lidar has a very high measurement speed and offers very high resolution and point densities. This allows for collections over very wide areas. The trade-off is in precision and the high false-alarm rate of the data. The inability to determine the total propagation of uncertainty is an undermining factor, and the scan pattern is limited due to the instantaneous field of view.
- Single-photon lidar offers improved precision over Geiger-mode and a lower false-alarm rate. Accuracy is similar to and measurement speed is a fraction of Geiger-mode.
- Bathymetric lidar uses a blue-green wavelength of light to penetrate water. This technology has been used for coastal and riverine mapping applications. In recent years, suppliers have introduced topobathymetric lidar sensors, capable of data collection over both land and water. Specialist bathymetric systems, however, can penetrate water to several tens of meters in good conditions, so the goal is to use lidar closer to shore, where operation of vessels equipped with multi-beam sonar is less safe.
- IfSAR, while much lower in vertical accuracy than lidar, is an effective tool for data acquisitions in challenging environments such as Alaska, due especially to its wide-area and through-cloud data collection characteristics. In addition to interferometry to determine range and elevation data, SAR offers both amplitude and polarimetric data, which yield a wide range of insightful data products. Orthorectified radar images are an easily derived, useful byproduct of the generation of elevation data.

Traditional analog lidar records only discrete echo signals and provides limited feature parameters. Full Waveform Lidar (FWL) records the backscattered echo in the form of a waveform that provides additional information. FWL is logged at very small intervals and thus obtains more footprints, echoes, and a precise definition of the actual situation. FWL is powerful but data-heavy with a cumbersome processing regime. A variation of FWL is “online waveform processing,” which is fast and highly accurate when sophisticated algorithms are exploited. This digital signal processing allows high ranging accuracy, high precision, multi-target resolution, clean point clouds, and improved classification and filtering. The 3D Nation Study documented that only 2% of the mission critical activities require FWL for topographic elevation data collection and processing. However, with the advent of AI/ML, “online waveform processing” provides the basis for improved data products for 3DEP and should be investigated for its potential contributions.

The 3DEP has continually investigated a range of data-collection technologies and hybrids such as photogrammetry and lidar combinations. Elevation data was derived photogrammetrically for almost a century before airborne lidar became commonplace and photogrammetric techniques have improved immensely over the decades. Many of the 3DEP partners, such as cities, routinely acquire imagery as well as lidar. Additionally, there are bathymetric technologies that could assist USGS's mission. Promising image processing techniques leverage deep learning; emerging satellite capabilities and new constellations provide lidar, imaging and SAR; and uncrewed aircraft systems with powerful cameras and lidar sensors are coming to maturity. The committee encourages the continuation of investigation into these and other new technologies to determine if they meet program requirements. This should include consideration of how combinations of technologies can be tuned for different landscapes. The benefits of evolving technologies may enter the program both through data acquisition contracting and proposed Ecosystem concept.

Elevation-change data is of increasing interest and IfSAR is ideally suited to provide this routinely. More satellite constellations, including small sats, are coming on orbit with relevant sensors, and processing has improved. Local collects using UAV-lidar are another, complementary approach to generating elevation-change data.

Project Data Contracting, Acquisition, Processing, and Timelines

The BAA process mentioned above is the approach used by 3DEP to solicit data acquisition partnerships from the broadest possible stakeholder community. For the FY24 cycle, the process will be revised and streamlined in a new structure called the 3DNTM Data Collaboration Announcement (DCA) which is planned to be released in September, 2023. The process will be similar to the BAA. Like the BAA, the DCA process will invite proposals from applicants who wish to propose a partnership with 3DEP to fund lidar data acquisition and the production of lidar-derived elevation products. Applicants may fund an acquisition project through the USGS GPSC, or they may request 3DEP funds to apply towards a lidar data acquisition project where the requesting partner uses its own contracting vehicle. Federal agencies, State and local governments, Tribes, academic institutions, and the private sector are eligible to submit proposals. Federal 3DEP partnerships are also developed in the 3DEP Working Group and carried out through Interagency Agreements. Finally, partners may also contribute 3DEP-specification-compliant data they have collected independently. Contributed data are quality assessed for inclusion in the national 3DEP holdings.

USGS's preferred method of data acquisition is through the GPSC, a multiple award acquisition vehicle that leverages the teams of firms on the contract for services needed to accomplish 3DEP data acquisition. The contracts include acquisition, processing, and quality assurance of lidar and other source geographic data. These contracts are in place and have been awarded through a competitive process. Firms on the GPSC have been selected based on their qualifications and performance in providing the professional services needed for 3DEP.

The GPSC is an indefinite delivery, indefinite quantity (IDIQ) contract that helps to streamline the contract process and speed service delivery. To ensure data quality and efficient development of standard products and services, the USGS prefers that partners use GPSC when possible and practical. Approximately 85% of the total funding for 3DEP data acquisition between 2015-2022 went through GPSC. This contract mechanism is also offered as a service for acquiring elevation or other geospatial data for external organizations who are not seeking additional funding from USGS.

The GPSC contractors are experts in processing raw airborne lidar data. They primarily make use of off-the-shelf software products, which, like the lidar systems themselves, are enjoying incremental improvements as time passes. The introduction of artificial intelligence, especially in the form of deep learning, is increasing the productivity of end-users of these software tools. The contractors' competitive advantages rest primarily on two aspects: the expertise of their employees and their firms' abilities to weave the components of the workflow together into quality-based, productive, seamless continua.

Current 3DEP project lifecycles and timelines are complex and typically range from 18 to 24 months (Figure 4). As in any project, if various steps are not completed correctly, the process takes longer. Contributing factors include time needed to develop partnerships and agreements, Federal budget, contracting process and timelines, flying season, weather and atmospheric conditions, data correction cycles with contractors, and Tribal notification timelines. Although most data deliveries fall within agreed-to task-order timelines of 18-24 months, there are situations in which 3DEP funding partners require more rapid delivery. This forces some States, cities, and other government entities to go outside of 3DEP to meet their

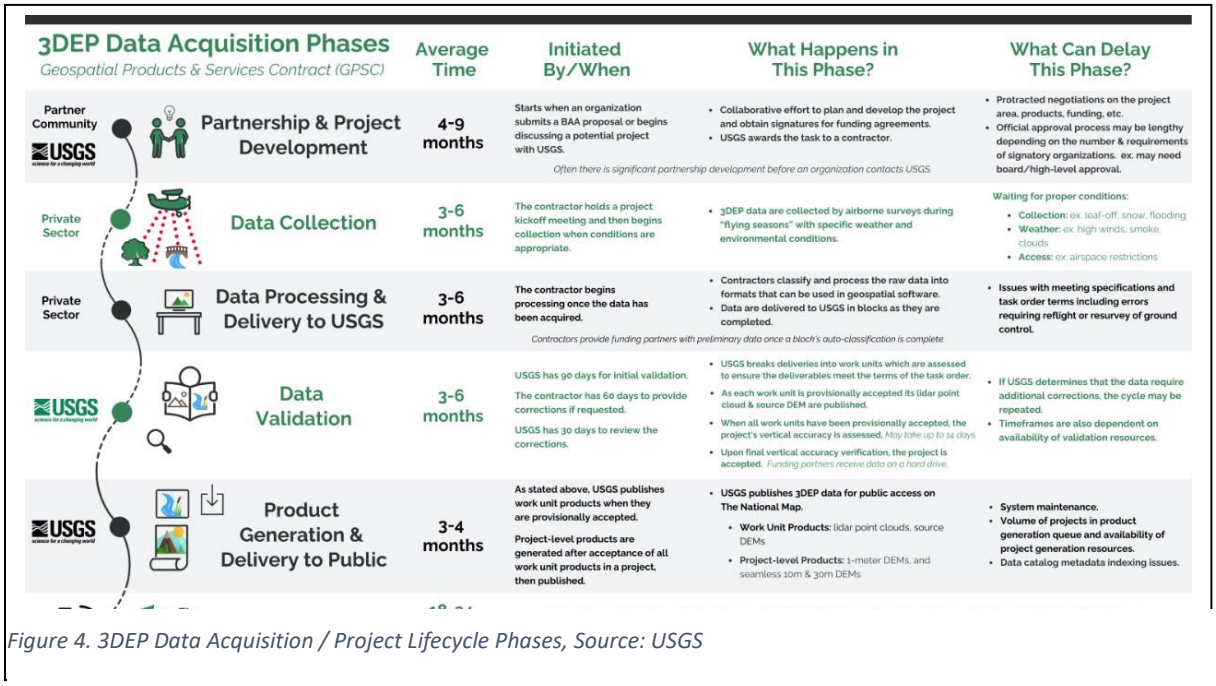


Figure 4. 3DEP Data Acquisition / Project Lifecycle Phases, Source: USGS

needs. For example, some counties and other organizations in California formed consortia to acquire lidar for wildfire management in advance of 3DEP coverage.

Timeliness of data delivery is currently being studied within USGS, and the decision has recently been made to have the contractors deliver preliminary data to the funding partners early in the processing phase. Additional progress on the reduction of turnaround time will be important to the continued success of the program. While it is critical for 3DEP to define and enforce a rigorous data validation process, the process must be analyzed within the context of government and private sector contractor capacities if it is to be both rigorous and efficient. It will be important for USGS to actively socialize and promote program enhancements such as a self-validation tool for GPSC contractors to use prior to USGS final review to help facilitate earlier access to data by funding partners and the public at large.

USGS has built a workforce, tools, and workflow to perform 3DEP data validation. The final acceptance function is inherently governmental in nature. However, there is precedent for peer-validation for other data types, such as ortho imagery, which are also contracted through USGS using GPSC. One item of concern is how the GPSC contractors will be able to simultaneously support validation of other 3DNTM programs about to come online (i.e., inland bathymetry and 3DHP). This could put additional stress on the contractors' validation system.

Action and communication are key to overcoming what might become a program execution deficiency. As a recommendation to improve the current situation, USGS should collaborate with its contractors to identify elements of the validation process that can be performed by the contractor prior to delivery to USGS validation (i.e., self-certification) to speed up the process. Changes in the validation process would also need to be vetted with partners who depend on USGS to ensure data quality.

TRENDS AND DEVELOPMENTS IN DATA DISSEMINATION

The USGS 3DEP data is available to be downloaded free of license or other restrictions. This democratization of data has enabled everyone, regardless of technical background, to download 3DEP data, access it, work with it, and transform it into geo-information to make informed decisions. Public and private entities can apply their analytics for their own benefit. 3DEP, in a way, is a geo-data public utility. The data has been collected to 3DEP standards and is authoritative. The data is available in LAS standardized binary format for 3D point-cloud data. Also provided is metadata, which describes the data structure.

The 3DEP program is a world leader in the dissemination of data. This approach provides data models and exchange formats for many different analytic tools, including AI/ML, modeling and simulation environments, and some feature identification approaches. Overall, 3DEP has paved a path for a rich consumer experience. Availability, accessibility, and distribution mechanisms continue to advance vigorous data dissemination developments.

Access to Lidar Data Products

First-generation 3DEP products are Quality Level2 (QL2) or better (Table 1) lidar point clouds and DEM, available through The National Map. IfSAR orthorectified radar intensity images (ORI), Digital Surface Models (DSM), and digital terrain models (DTM) are available in Alaska through The National Map and the USGS Earth Resources Observation and Science (EROS) Center. Through the life of 3DEP, users have grown accustomed to accessing and using these products. Reliable delivery has incorporated new technologies and techniques, including expanded cloud use. As use expands, new and revised needs have emerged. The 3D Nation Study documents clear user-demand for readily available higher-resolution lidar data (QL1 or better); digital elevation models, digital terrain models, classified point-cloud data, digital surface models; hydro- flattened, hydro-enforced, and hydro-conditioned DEMs; and seamless DEMs and lidar point clouds. The requirement of a seamless 1-meter DEM for derivation of hydrography from elevation data will be a significant driver for development and maintenance of products in the next generation of 3DEP. The next generation of 3DEP should seriously consider including these upgrades.

Table 1. Lidar Data Quality Level (QL) requirements as described in the 3DEP Lidar Base Specification. www.usgs.gov/3d-elevation-program/topographic-data-quality-levels-qls

Quality Level	Data Source	Vertical Accuracy (RMSEz) in centimeters	Nominal Pulse Spacing (NPS) in meters	Nominal Pulse Density (NPD) Points per square meter	Digital Elevation Model (DEM) cell size (meters)
QL0	Lidar	5 cm	<= 0.35 cm	>= 8 pts/sm	0.5 m
QL1	Lidar	10 cm	<= 0.35 cm	>= 8 pts/sm	0.5 m
QL2	Lidar	10 cm	<= 0.71 cm	>= 2 pts/sm	1 m
QL3	Lidar	20 cm	<= 1.41 cm	>= 0.5 pts/sm	2 m
QL4	Imagery	139 cm	N/A	N/A	5 m
QL5	IfSAR	185 cm	N/A	N/A	5 m

Quality Level (QL) requirements are based on two components: the nominal pulse spacing/density, and the vertical positional accuracy.

3DEP Ecosystem Advances

In its first generation, 3DEP focused its resources and activities on acquiring, processing, and delivering a consistent nationwide dataset of QL2 or better lidar for the conterminous States and QL5 IfSAR in Alaska. With that task nearly complete, 3DEP can expand its mission in the next generation program by facilitating access to a variety of data and tools to support the even broader needs of the user community. The program will continue its primary function of acquiring and delivering standard baseline elevation data for the Nation. The success of 3DEP's first generation spawned a myriad of sensors, data formats, data processing approaches and applications. Current 3DEP confronts the challenge of that success: more demand for basic credentialed and ready-for-analysis data delivered in a timelier fashion.

The next generation of 3DEP should take advantage of these advances by adopting a development and coordination role, providing a central location where users can find the authoritative data and share useful data that might not meet all the 3DEP specifications, including quality and "fit for use" assessments provided by producers of the data. Data analysis

tools and code could also be shared. One way to do this without placing an undue burden on USGS would be to develop a system that connects to datasets in other locations (e.g., State governments, other Federal agencies) where users can access all kinds of elevation data. The US Interagency Elevation Inventory (USIEI)[11]which is an interactive map showing footprint, data type, and basic metadata, but not direct access to data could serve as the starting point.

In its draft program plan identified in the Introduction, USGS proposes creating a 3DEP Ecosystem that would serve the functions described above. The Ecosystem concept would expand on the capabilities of finding who owns various elevation data available in the U.S. Interagency Elevation Inventory and enable USGS to continue its role of providing authoritative data while allowing users direct access to all data and derivatives that meet their needs and tools in a single interface to render these data more useful. While 3DEP would incur expenses for staff and infrastructure to build and maintain the Ecosystem, those costs may be wholly or partially offset by efficiencies in sharing data across government agencies at all levels.

Although 3DEP is focused on structured data collections, the program has shown flexibility to include provisions for emergency response data acquisitions. By cooperating with rapid collections, the program maximizes the value of this data for inclusion into 3DEP holdings. Making a formal space within 3DEP for rapid response collections by dedicating funds and adding the data to the 3DEP Ecosystem, as proposed in the 3DNTM draft plan, would be a useful advance toward providing data quickly to address a pressing need.

All manufacturers have made improvements to airborne lidar sensors, including the ability to collect higher-resolution data at higher altitude with more widely spaced flight lines, and hybrid systems that collect vertical and oblique images simultaneously with the lidar, in order to provide more economical data acquisition. UAV-mounted lidar sensors generate high-density, high-accuracy data over small areas at relatively low cost. UAV data collections have become common for certain applications. Mobile mapping systems (MMS) consisting of sensors and cameras mounted on road or rail vehicles are now mainstream. Whether or not such collections are funded by 3DEP, it is recommended that USGS consider a way to absorb such data into a 3DEP Ecosystem.

Dissemination Benefits of 3DEP Alignment with the National Spatial Data Infrastructure (NSDI) and Community-Accepted Standards

Well-intended collection of any geospatial data set misses the mark of interoperability with other existing data sources and efficacious reuse if it lacks adherence to accepted standards and specifications. Such circumstances continue to occur and limit benefits for a community of users. Under the leadership of USGS, 3DEP is responsible for the production and stewardship of the nationwide National Geospatial Data Asset (NGDA) elevation theme as outlined in OMB Circular A-16 and the Geospatial Data Act (GDA) of 2018. 3DEP adheres to NSDI principles with a governance structure based on GDA requirements including a strong emphasis on

[11] https://coast.noaa.gov/inventory/

partnerships, collection, and processing strategies, and the "collect once, use many times" NSDI principle. To further aid in assuring adherence to these principles, key 3DEP coordination and collaboration activities have been established:

- A FGDC 3D Nation Subcommittee jointly led by USGS and NOAA as OMB Circular A-16 co-leads has been established to ensure coordination of 3D elevation requirements across the Federal government.
- A 3DEP Executive Forum and operational Working Group promote dialog and collaboration on strategies for the implementation and sustainability of 3DEP for stakeholders across government and the broader community.
- A comprehensive nationwide and publicly available U.S. Interagency Elevation Inventory (USIEI) has been implemented to raise awareness, encourage access to and use of existing elevation data, and to avoid duplication of effort.
- The SeaSketch U.S. Federal Mapping Coordination site is a NOAA hosted web-mapping tool used by Federal agencies and 3DEP partners to collaborate on elevation data requirements and acquisition.
- NOAA and USGS conducted the comprehensive 3D Nation Study to document the requirements and benefits of 3D elevation data and are using the results to inform their program directions.

USGS is also taking steps to establish the 3D Elevation FICC as mandated in the NLPA. The new committee will be expanded in scope to the 3DNTM and will incorporate the 3DEP Executive Forum as the executive governance for both the elevation and hydrography themes.

A key to success of the 3DEP is adherence by partners to the LBS, an FGDC-compliant standard, which provides requirements for 3DEP data collection to assure data delivered to users meets expectations of quality. Other industry and international standards, both existing and emerging, are critical to the 3DEP system operations including data ingest, processing, maintenance, access, and distribution. Appendix 3 provides a detailed list of standards and data formats used by 3DEP. This Appendix also lists emerging standards that have potential for streamlining 3DEP processes as well as to support next generation 3DEP capabilities.

Many Federal government organizations such as USGS have access to the industry and international standards community resources through membership in organizations such as the Open Geospatial Consortium (OGC) and the International Organization of Standards (ISO). As members, Federal government organizations, through designated representatives, work openly with industry and user community experts, both nationally and internationally, to influence and leverage new and emerging standards. This participation would benefit 3DEP operations and evolution. However, USGS 3DEP representation in these Standards Development Organizations (SDOs) at present is minimal and insufficient to properly influence emerging standards development activities in support of 3DEP requirements.

From the Subcommittee's review of 3DEP, it appears that only limited use of community pilot initiatives and technology development "sprints" are being applied to help accelerate alignment of the user and technology provider communities to current and emerging standards and capabilities. Such initiatives represent proven practices that can help to secure user and technology community expertise and resources to rapidly test and prototype new and innovative solutions for improved efficiency of 3DEP operations. These initiatives also help to quicken the pace of development to operational readiness. Pilots and development sprints of relevance are routinely being conducted within SDOs, open-source associations, and innovation labs such as The Opportunity Project (TOP)[12], managed by the U.S. Census Bureau. Such opportunities for 3DEP would broadly leverage community expertise to advance objectives for the next generation of 3DEP.

Within the scope of the NSDI (processes, practices, systems, data, resources, people), there appears to be no clear documentation of the 3DEP architecture that identifies the overall workflow, system components, processes, and implemented standards. Availability of such an architecture document can help communicate interoperability requirements across the producer and user community as well as minimize the time and effort related to the mobilization of future 3DEP capabilities.

Integration with and Derivation from Other Data

The 3D Nation Study demonstrated a strong need or desire for integration of elevation data with other kinds of data, including:

- Imagery – 96% of users in the 3D Nation Study state that integration of elevation data with imagery is required or highly desired. Integration in this context could mean flying imagery and elevation data at the same time, or in the same season.
- Elevation-derived hydrography -. Hydrography data can be directly derived from elevation data, providing an unprecedented view of how water moves over the landscape, a view that is critical to water resource use and management, habitat preservation and restoration, and flood management and mitigation. The need for hydrography data will become a driving force for frequently updating elevation data. The 3D Nation Study found that 84% of users required or highly desired elevation data integration with inland surface water features, 74% required or highly desired integration with wetlands, and 69% required or highly desired integration with bridges and culverts. Provision of high quality, up-to-date hydrography data will require close collaboration between 3DEP and 3DHP.
- Inland bathymetry - 62% of users in the 3D Nation Study indicated a need for inland bathymetry data. The development and integration of inland bathymetry (principally from airborne lidar with supplemental water-based sonar) will be a core element of the next generation of 3DEP and offers a significant opportunity for the private sector to

[12] The Opportunity Project | The Opportunity Project (census.gov)

support evolving requirements and applied use. While USGS is exploring options for collecting bathymetry, such as structure from motion (well known as SfM) from optical satellites, it is important to understand that these options would only be used in situations where access is impossible with airborne or waterborne assets. While cost-effectiveness is well documented, the resolution weakness cannot be ignored from a user's perspective.

Additionally, many kinds of local high-density surveys offer valuable vertical information, from those done by the GSPC contractors for non-USGS clients to surveys by other contractors, as well as Federal, State, and local governments. There are UAV projects using imagery and lidar, numerous collects using mobile mapping systems, and even ground surveys by professional land surveyors that include height points. Although these potential suppliers might be willing to sell inexpensively to USGS, the fit-for-use qualifications and government openly-available data policies would require well-structured checks on intellectual-property issues, peer review, QC, and any decisions about transforming local collections into the 3DNTM coordinate reference system or requiring suppliers to do that. Metadata reports on these topics provided within the Ecosystem could provide a way to characterize limitations on use and identify standards that have not been met, allowing users to make judgments about risk and its mitigation.

Data Storage

Data storage and archive management is a critical back-office issue for data accessibility and dissemination. 3DEP has generated nearly nationwide QL2 lidar data that must be retained. Currently more than 52 trillion data points are being distributed and the number is increasing daily. Highest-quality QL1 and QL0 data required to meet next-generation needs will necessitate even more storage, as will new derived products mentioned above. Elevation and land-use change detection at the local and regional scale, obtained by comparing different generations of lidar or SAR, are a growing element of many user applications. Therefore, prior datasets must be retained even as new data is being generated. The Subcommittee recommends that 3DEP be provided with resources to secure sufficient and permanent data storage.

TRENDS AND DEVELOPMENTS IN DATA USE

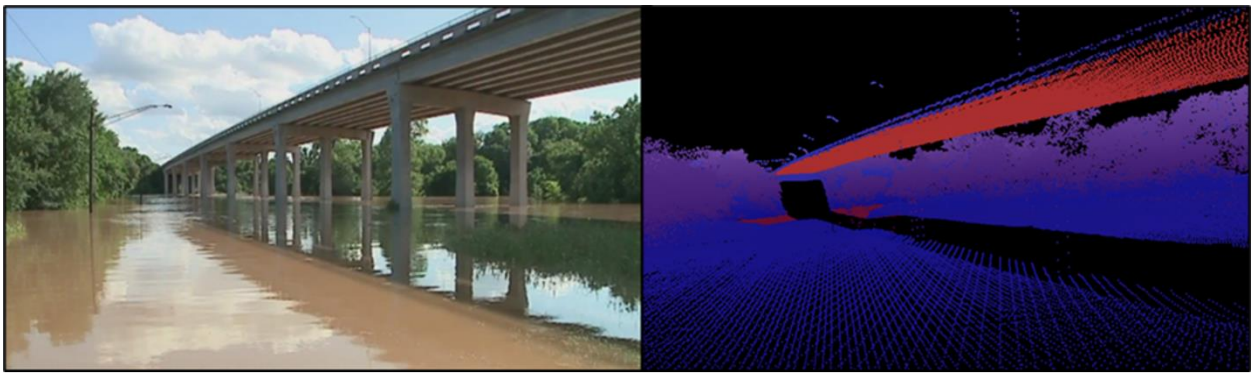
3DEP informs critical decisions made across our Nation every day that depend on elevation data, ranging from immediate safety of life, property, and environment to long-term planning for infrastructure projects. Improving hydrologic forecasting models and flood-risk maps with reliable elevation information has a positive impact on preparation for natural disasters. Understanding elevation data assists in the management of critical infrastructure, detecting land surface changes from natural processes, such as landslides and erosion and human activities, and supporting sensor-rich smart infrastructure including transportation and utility grids. Previously unanticipated applications include the use of high-resolution 3D elevation data

from 3DEP in the development of digital twins of the natural and built world. Growth of the program towards greater density of data and faster refresh cycles will help to meet emerging needs. These applications will require innovative data acquisition schemes, in which 3DEP has already demonstrated competence.

The following examples illustrate both routine and innovative uses of 3DEP data and emphasize the benefits of the 3DEP program.

State of Texas

A critical component of real-time response to flood events is to understand flood impact on the road and bridge system. The Federal Emergency Management Agency (FEMA) has invested several billion dollars in digital floodplain mapping, primarily for flood insurance purposes to assess flood risk to building infrastructure. However, there has been little emphasis on flood risk to the transportation system. Through a partnership with the Texas Department of Transportation, the Center for Water and the Environment of the University of Texas at Austin has begun work to characterize the elevation of bridge decks using 3DEP lidar point cloud data (Figure 5). Flood inundation mapping is normally developed using bare-earth elevation models with bridges removed. This work will allow maps and models to include inundation of bridges during flood events. Texas has about 25,000 bridge spans over water in the National Bridge Inventory, which catalogs all bridges greater than 20 feet in length. The National Bridge Inventory includes about 500,000 bridges over water in the continental United States that could be similarly characterized.



There are 893,965 lidar points on the bridge deck, which is adequate to define its vertical elevation above the river, and thus its risk of flooding if there is a flood moving down this portion of the Colorado river.

Figure 5. 3DEP lidar point-cloud representation of the bridge deck for highway TX 95 over the Colorado River near Smithville, Texas.

Sonoma County, California

In Sonoma County, California, local and regional governments, agencies, and non-governmental organizations (NGOs) derive important benefits, including significant cost savings, from 3DEP data and products by augmenting local planning efforts with high-resolution data that supports objective and effective prioritization of investments.

Many application instances are highlighted on the Sonoma Veg Map website[13]. The program also benefits from local and regional partnerships leveraging Federal investments with the allocation of local and regional matching funds, local staff resources to work with USGS staff, and development of derivatives related to planning, implementation and monitoring of projects including water quality and supply, built infrastructure, and ecosystem conservation.

Leveraging local and regional partnerships and investments provides an opportunity for the 3DEP program to expand its impact and cost-effectiveness. Regional USGS liaison roles should continue and expand the development of partnerships and consortia. Funding should be provided in the form of grants or contracts to support entities, which can work with the regional USGS liaisons to form those teams.

Implementing this recommended approach with other States and regions would result in increased local and regional appreciation of 3DEP. Leveraging Federal investments through the allocation of local and regional matching funds and designation of local staff resources to work with USGS staff, will promote more development of derivative products and provide improved service. This case example includes impact to planning, implementation and monitoring of projects including water quality and supply, climate change and disaster resilience, as-built infrastructure insights, and ecosystem conservation.

State of North Carolina

North Carolina's statewide imagery program provides another relevant example. Starting in 2010, the North Carolina 911 Board has funded the collection and production of high-resolution orthoimagery for North Carolina. The State was divided into four project areas with imagery data collection performed in one project area per year. The statewide imagery program supports the 911 Public Safety Answering Points in North Carolina and is used for other applications including engineering, land surveying, urban and regional planning, county tax revaluations, environmental assessment, mitigation projects, and economic development. A DTM/DEM is required to orthorectify the imagery to reduce distortion due to terrain effects. The North Carolina Floodplain Mapping Program has collected statewide QL1 and QL2 lidar data, which provides the elevation data needed to address imagery orthorectification requirements. This is one example of a statewide lidar project that can be used to support a statewide imagery project. The statewide lidar data is a key dataset for the completion of the imagery project each year.

Post-Event Lidar Data Collection

Post-event lidar data collection can be used as a change detection tool in storm-impacted areas for such items as the determination of beach erosion and the amount of debris. The FEMA recovery team depends heavily on having lidar available to help determine both the financial considerations and the severity of impacts in affected areas. FEMA has recently published elevation guidance to be used for flood risk to provide guides for procurement of either

[13] https://sonomavegmap.org/

leveraged or newly acquired elevation data, requiring compliance with QL2 data as defined in the USGS Lidar Base Specification[14].

Precision Agriculture

High-quality lidar data provides value to users in agriculture and forestry. One key benefit is the ability to produce topographic maps of agricultural fields. Seemingly minor changes in elevation can affect the ability of the soil to hold moisture. These changes in moisture content in the soil can have a significant impact on plant health or vigor and ultimately impact crop yield. Topographic maps can also be developed at the field or farm level to aid in the planning of terraces for erosion control. Elevation data within streams and ditches can be used to monitor drainage capability, flowing water capacity, catchment areas, and erosion potential. Lidar is also used to measure plant height in fields and orchards and vineyards to determine the amount of biomass above the ground. It can also be used to develop stand counts for various crops. Similar applications in forestry include stand counts for trees as well as estimating the area and volume of the tree crown. In applications where lidar can penetrate the canopy, estimates of branch or trunk diameter can be made. New research is active and expanding; using lidar will undoubtedly yield more applications in agriculture and forestry. As an example, plant phenomics is a new way to connect environmental research with plant genomics, one aspect of plant management and breeding. Lidar offers a new tool for 3D plant monitoring across seasons and science disciplines[15].

COST AND EFFECTIVENESS OF THE 3D ELEVATION PROGRAM

The examples above describe multiple methods to address a variety of issues by using elevation data. NLPA requires the 3DEP subcommittee to assess the "effectiveness of the 3D Elevation Program in carrying out the activities described in subsection (a)(1)" of Sec. 5. 3D ELEVATION PROGRAM. The previous and following sections explain how well the 3DEP is meeting the general criteria described in the NLPA for this assessment:

A. 3D coverage for the United States;
B. coordination and facilitation among Federal departments and agencies and non-Federal entities;
C. production of standard, publicly accessible elevation data;
D. promotion of the collection, dissemination, and use of the data among Federal, State, local, and Tribal governments, communities, institutions of higher education, and the private sector through agreements, reliable spatial data infrastructure, coordination with the 3D Elevation Federal Interagency Coordinating Committee, and improvement of the accuracy and efficiency of the program.

More details appear in the legislative language.

[14] https://www.fema.gov/sites/default/files/documents/fema_elevation-guidance_112022.pdf
[15] https://roboticsbiz.com/advantages-of-lidar-sensors-in-agriculture/

The extent of coverage across the Nation was well described in the Introduction to this report and captured visually in Figure 1. USGS contracting and validation processes have created a cooperative collection, processing, and dissemination methodology that establishes a fully national coordination and collaboration environment to assure production of quality data. Technology trends that might improve the program are carefully considered and incorporated wisely. The program team also plans for future improvements, involving producers and users in shared discussions about the next generation 3DEP.

3DEP Funding to Achieve Effectiveness

The inputs to the community-wide 3DEP budget, illustrated graphically in Figures 6 and 7, include:

- **USGS 3DEP funding** – part of the Core Science Systems - National Geospatial Program line item that funds 3DEP and other components.
    - The USGS 3DEP budget funded about 32% of the total costs of 3DEP during FY15-22 which includes data acquisition funding that is used to attract and leverage partner investments and funding to operate the program, including program management, data processing and delivery. USGS has received budget increases in previous years for data acquisition for a number of specific projects.
- **Partner funding** – About 64% of funding for the total cost of 3DEP between FY15-22 was contributed by Federal, State, local, Tribal, and other partners. Partner funding is applied solely to data acquisition. About 81% of data acquisition funding is from Federal and 19% from non-Federal sources.
- **Supplemental funding** – in addition to appropriations, USGS 3DEP has received the following supplemental funding that has been used primarily for data acquisition with 10% applied to program management, data processing and delivery:

- **Supplemental hazards and wildfire funding** – The USGS received $18.3M in FY18, $10.2M in FY19, and $5.3M in FY22 in supplemental funds for lidar
- acquisition for areas impacted by hurricanes and wildfire disasters.
- **Bipartisan Infrastructure Law funding** – Through the USGS Earth Mapping Resources Initiative, 3DEP received $5M for data acquisition in FY22 and FY23.

- **Inflation Reduction Act (IRA) funding –** In FY23, USGS received $23.5M in IRA funding to help achieve complete national 3DEP baseline coverage, to ensure efficient and timely data processing and delivery, and support research and acquisition to help establish the 3D National Topography Model (3DNTM). For example, in FY23, $6M in IRA funds are being used to accelerate completion of the 3DEP baseline dataset.

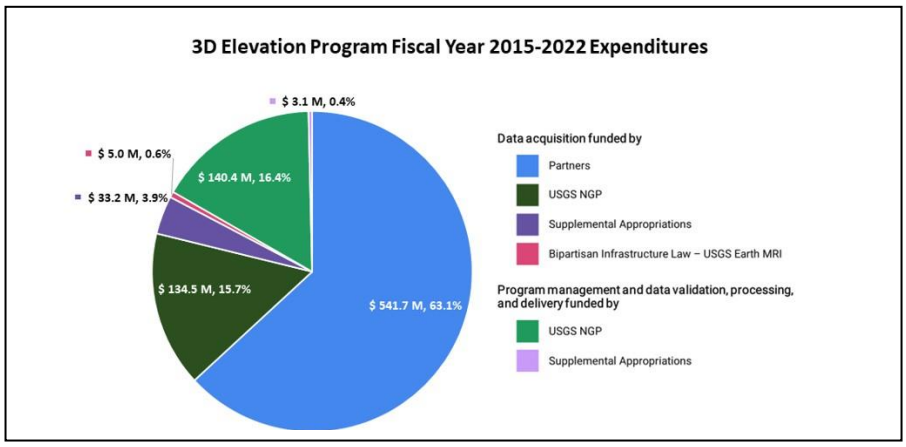


Figure 7. Breakdown of Total 3DEP Expenditures for Fiscal Years 2015 - 2022

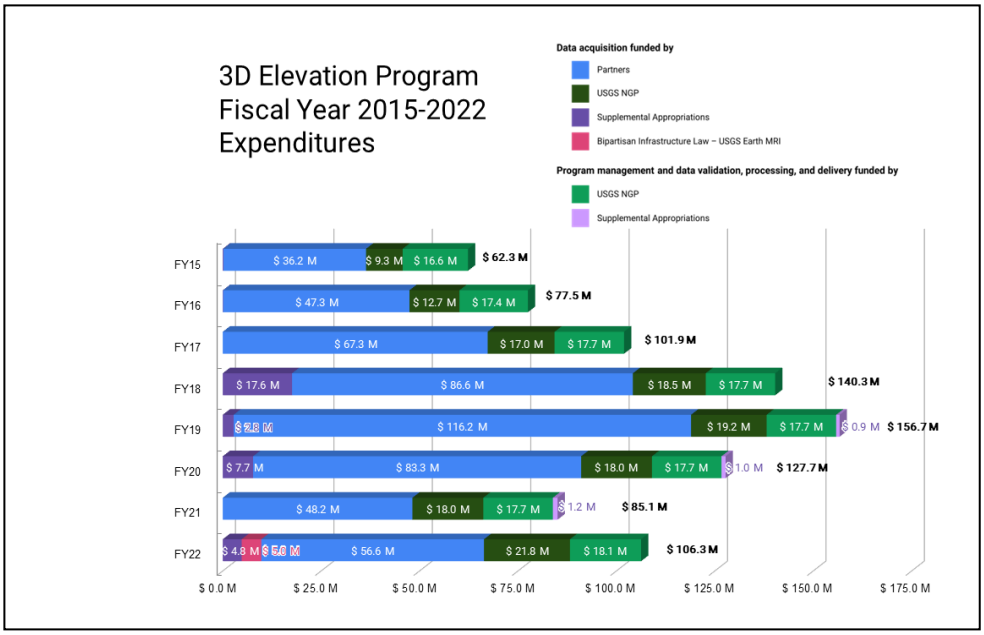


Figure 6. Breakdown of Annual 3DEP Expenditures for Fiscal Years 2015 - 2022

USGS Budget Priorities Now into the Future

USGS designed the program to meet documented user requirements, and on an average annual budget of about $36M attracted and managed $542M of partner funding between FY15-22 to reach 89.5% of the Nation with 3DEP data available or in progress by the end of FY22. The leading priority was to maintain a clear goal and focus resources on completing the nationwide 3DEP baseline dataset, primarily investing in data acquisition and processing. Key to developing partnerships has been establishing and implementing governance and best practices among the Federal community in the 3DEP Working Group and Alaska Mapping Executive Committee, and with the State level via NSGIC and Association of American State Geologists (AASG) representation to the 3DEP Working Group. LBS has been managed in association with the governance process and has helped to maintain consistency and allowed for the program to ingest data from a variety of sources.

While the 3DEP has been successful in focusing resources to keep pace with the goal for nationwide 3DEP coverage, the current USGS budget has limited further innovation or development of additional products and services, or expansion into areas such as OGC standards. Funding for program management, data processing and delivery has remained relatively flat while the volume of data flowing through the system has risen dramatically due primarily to partner funding and modest budget increases for data acquisition. This has had multiple impacts including pressure on data validation and processing resources and IT infrastructure.

The next generation 3DEP program design is even more ambitious than the national baseline 3DEP goal, with 3-4 times as much funding needed to increase quality levels and refresh cycles, and to implement the 3DEP Ecosystem as a major new capability. Budget pressures will be even greater in the next generation program, and recommendations for additional staffing or other efforts must be balanced against the funding needed for data acquisition to meet partner requirements.

Effectiveness Measured by the Economic Benefits of 3DEP

Studies by USGS and its partners, including the 3D Nation Study, which built upon NEEA, speak to the value and importance of the 3DEP program and products. NEEA highlights numerous business use cases and benefits associated with enhanced elevation data for the Nation and includes a top ten list of Expected Benefits (Figure 8). USGS announced on its website that the 3D Nation Elevation study documents $13.5 billion of benefits for 1352 mission critical requirements.[16]

Stakeholders for both studies include Federal, State, local, Tribal, non-profit, academic, and private organizations, and agencies.

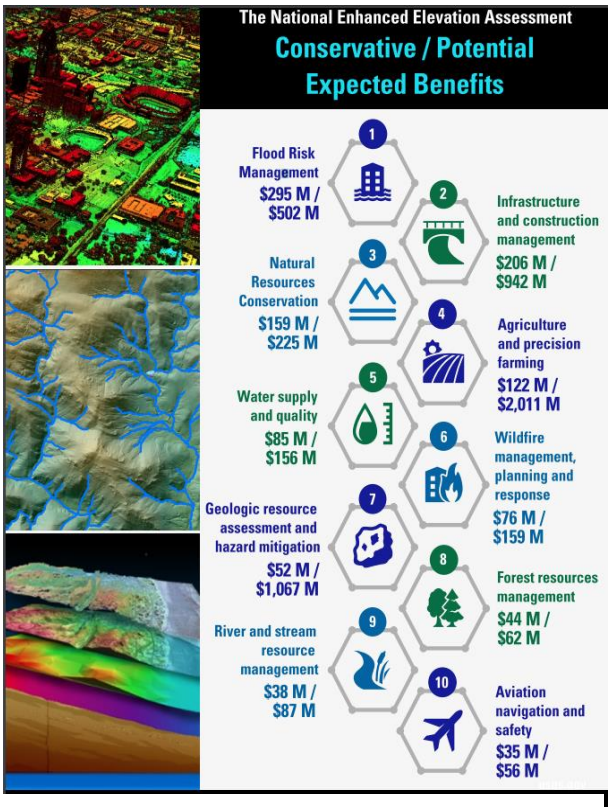


Figure 8. NEEA Potential Benefits

Effectiveness Measured by the Value of 3D Elevation Data for Risk Reduction and Environmental Management

Nationwide coverage of key geospatial information including high-resolution 3D elevation data is a key requirement to properly prepare for, respond to, and mitigate the effects of landslides, floods, fires, hurricanes, and other natural disasters. Risk-reduction tools use this data along with other geospatial data layers to improve disaster resilience by better understanding localized vulnerabilities and degrees of exposure of communities and assets to diverse kinds of disasters. High-resolution 3D elevation data has other uses in the

> ***In 2022, there were 18 separate weather and climate related disasters with losses exceeding $1 billion, with 474 deaths recorded for these events. The total Consumer Price Index (CPI) adjusted cost for these events was $175.2 billion, making this the third most costly year on record. The total cost for the last five years ($611.8 billion) is approximately one-quarter of the total cost since 1980 ($2.55 trillion).***
>
> *Source: NOAA National Centers for Environmental Information, www.ncei.noaa.gov/access/billions/ (as reported 17 June 2023)*

[16] https://www.usgs.gov/3d-elevation-program

public and private sectors, including development of smart and safe cities, agriculture and precision farming, wildlife habitat management, forest resources management, riverine and flood management, climate change impact assessment, navigation, and related benefits associated with risk management and insurance protection[17].

Leveraging Public-Private Partnerships

Several other reports and recommendations published by NGAC address 3DEP (Appendix 2). Among them is a December 2020 report identifying Public-Private Partnerships[18] (P3) as one important approach to advance the National Spatial Data Infrastructure (NSDI) by establishing and sustaining effective public-private collaboration. The report cites the potential for greater risk and reward sharing between government and industry as part of innovative partnerships where government benefits from capabilities and resources of industry to deliver public services, while offering the private sector an opportunity for marketization of products and services. The report defines P3s as (NGAC, p.6, 2020):

> *"A long-term agreement between one or more public agencies (Federal, State, and/or local) and private sector entity or entities that includes shared responsibility, risk, and reward among the parties. Through this agreement, the skills and assets of the private sector are employed in delivering a product, service, or infrastructure for use by the public at large."*

The paper cites 3DEP as an example of an Innovative Partnership with potential to become a true P3[19]. In a detailed assessment of national 3D requirements and benefits[20], and through the release of a multi-year BAA, 3DEP harnesses a broad array of State, local, Tribal, and not-for-profit partners who contribute funding, data, and related resources. As explained previously, 3DEP leverages the expertise and capacity of the private mapping firms that collect the data funded by the USGS and its partners. The NGAC P3 Report suggests that future industry technologies, collection strategies, funding tactics, and consortia arrangements may create additional opportunities for P3. Possibilities include:

- Partnering on government data acquisition
- Establishing government purchases to provide government and public access to 3D elevation data maintained by industry, with industry ability to license / sell versions of the data at higher resolution or more frequent refresh rates
- Generating revenue from other market applications including precision agriculture, flood forecasting/warning, insurance risk assessment and policy valuation, timber/forest resource management, and engineering planning.

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[17] 3D Nation Requirements and Benefits Study Appendix E – Business Uses, www.dewberry.com/docs/default-source/documents/3d-nation-elevation-requirements-and-benefits-study/appendix_e_business_uses.pdf?sfvrsn=7d81d167_1

[18] NGAC Report and use cases are available at: https://www.fgdc.gov/ngac/meetings/december-2020

[19] http://www.fgdc.gov/ngac/meetings/december-2020/ngac-use-case-3d-elevation-program-dec-2020.pdf

[20] http://www.dewberry.com/services/geospatial-mapping-and-survey/3d-nation-elevation-requirements-and-benefits-study

Coordination with Other Groups

The 3DEP program consistently leverages its governance process to receive input from partners and to further develop and define the program. This includes the 3D Executive Forum and the 3DEP Working Group with representation from 18 Federal agencies, NSGIC, and the AASG. 3DEP governance has been instrumental in selecting the program design, implementing best practices, managing the partnership process, and providing input to the specification and other technical decisions. 3DEP governance has resulted in about 65% of the program costs being invested by over 300 partners.

USGS notifies Federally-recognized Native American Tribes regarding the collection of lidar data for their reservation and trust lands. USGS leads Tribal notification for all projects that involve USGS funding or for any lidar data published on The National Map. USGS has sent over 1,000 Tribal notification letters since 2017. Tribes have provided a range of responses, from requests for copies of the lidar data for Tribal use, to requests to restrict public access to the high-resolution elevation products for Tribal lands. Tribes have also partnered with the 3DEP program. For example, several Tribes have provided funding to 3DEP for lidar acquisition, and USGS also has entered a contract with the Yurok Tribe to conduct a lidar survey for a portion of their reservation and ancestral lands in California.

In the future, representative expertise from other organizations would be valuable additions to 3DEP working groups. Examples include the American Society for Photogrammetry and Remote Sensing (ASPRS), the professional association responsible for developing standards for photogrammetric and remotely sensed data, information, and products, including those for lidar and IfSAR[21], and OGC, which represents over 500 businesses, government agencies, research organizations, and universities united by a desire to make location information findable, accessible, interoperable, and reusable.

THE NEED TO REVISE OR REORGANIZE THE 3D ELEVATION PROGRAM

The NGP has managed 3DEP in an effective and collaborative manner since its inception. The NGP has established ambitious goals for the program, communicated and collaborated effectively with a wide range of stakeholder groups, and has delivered impressive results with limited resources. It has established strong partnerships with Federal agencies, with other levels of government, and with the private sector. While the subcommittee does not see a need to revise or reorganize the program at this time, this report offers a set of recommendations to enhance the effectiveness of the program.

3D Elevation Federal Interagency Coordinating Committee

NLPA outlines a revised governance process for 3DEP with which 3DEP is mandated to coordinate. The new governance process requires the Secretary of the Interior, in coordination

[21] ASPRS Accuracy Standards for Digital Geospatial Data. https://www.asprs.org/a/society/divisions/pad/Accuracy/Draft_ASPRS_Accuracy_Standards_for_Digital_Geospatial_Data_PE&RS.pdf

with the Secretaries of Commerce and Homeland Security, to establish an interagency committee known as the ‘‘3D Elevation Federal Interagency Coordinating Committee’’ to better coordinate 3DEP data management across the Federal Government. The Interagency Coordinating Committee will include the following members (or their designees):

- Secretary of the Interior (Chair)
- Secretary of Agriculture
- Secretary of Commerce
- Secretary of Homeland Security
- Director of the National Science Foundation
- Director of the Office of Science and Technology Policy
- Director of the Office of Management and Budget
- The head of any other Federal department or agency, at the request of the Chair

The Interagency Coordinating Committee will coordinate with existing groups including the 3D Elevation Program Executive Forum, the Alaska Mapping Executive Committee, the 3D Elevation Working Group, the 3D National Elevation Subcommittee; and State offices. The duties of the Interagency Coordinating Committee will be to:

- Oversee the planning, management, and coordination of the 3DEP program.
- Develop and periodically update a strategic plan that establishes goals and priorities for the 3DEP program.
- Develop a detailed management plan to implement the strategic plan.

As of the publication of this report, the Department of the Interior and USGS have taken initial steps to establish the Interagency Coordinating Committee.

3DNTM Call for Action Part 2: Next Generation 3DEP

As mentioned in the Introduction, a draft paper is nearing completion that will detail recommendations for 3DEP and the community of producers and users to consider regarding important revisions to the current program. These reflect recommendations from the 3D Nation Requirement and Benefits study as well as other insights from leaders within the current program.

3D National Topography Model

“Topography is defined by terrain and water, each influencing and shaping the other. The 3D National Topography Model (3DNTM) is a new initiative that updates and integrates USGS elevation and hydrography data, and the relationships between them, into a 3D model to deliver higher-quality data and support improved geospatial analysis. The 3DNTM, including 3DHP and the next generation of 3DEP will provide foundational data to meet the most

demanding scientific requirements and enable data-driven decisions across user communities."[22]

THE MANAGEMENT, COORDINATION, IMPLEMENTATION, AND ACTIVITIES OF THE 3D ELEVATION PROGRAM

There are many examples of 3DEP effectively coordinating with other sectors, including State, Tribal and local governments, regional and local agencies, NGOs, and the private sector. This coordination results in leveraging 3DEP program investments (Figure 9), information sharing and messaging regarding the benefits of the program and enhancement of outcomes on the ground in communities. One factor in ensuring the success of this coordination is having an entity or individual that is knowledgeable about the 3DEP program, who can convene multiple local and regional entities, determine their needs and willingness to provide financial and other investments, and help the coalition to apply for funding under the Program. Having a partner "convener" can result in a much more robust application in response to a BAA (one that represents the interests of a broad diversity of entities in the geographic area of interest), and this same coalition will often provide significant matching funding to leverage 3DEP investments and will often continue to work together to develop funding for lidar derivatives and other assessment and analysis outputs. There may be opportunities for USGS or a partner foundation to fund "conveners" or "coordinators" across the country, to enhance the nationwide understanding of and access to the 3DEP Program by local and regional partners.

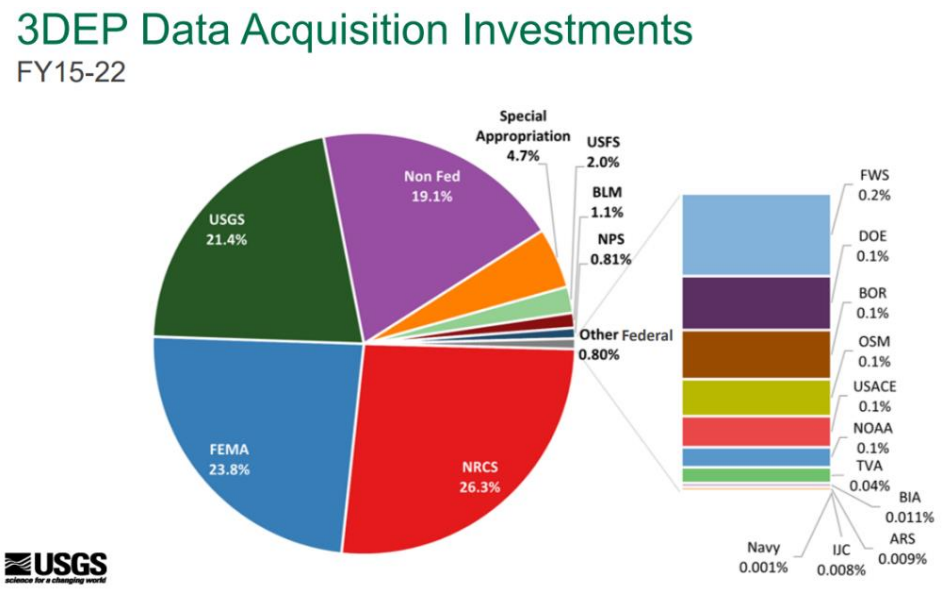

Figure 9. 3DEP Acquisition Investment Participation, Source USGS

[22] http://www.usgs.gov/national-hydrography/3d-national-topography-model-call-action-part-1-3d-hydrography-program

Encouraging Greater Participation from Non-Federal Partners

The above graphic shows the funding participation from various organizations between 2015 and 2022. 3DEP partner organizations have indicated a need for USGS to establish earlier and clearer communication with potential partners (State, local and Tribal government, universities, non-profit organizations, and agencies) to explain the program and processes for establishing a 3DEP agreement through the BAA and GPSC processes.

Regional Consortia

Partnerships with some non-Federal entities could be increased through the establishment of regional (sub-state) geospatial consortia. There are successful examples of regional groups sharing best practices and contracting for elevation data and all geospatial data.

As an example, the North Coast Resource Partnership (NCRP) is a collaboration of seven California counties and over 30 Federally-recognized Tribes, working together to enhance the quality of life in the 19,000 square mile North Coast Region of California. USGS recently awarded the NCRP $7 million in funding to fill in gaps in lidar coverage in Northern California. The BAA award included matching funds from the State of California ($3.5 million) and funds and other contributions from three local agencies in two counties, and the University of San Diego. The data developed from the 3DEP program award will be further leveraged by local, regional, State, and Tribal partners by the creation of an array of derivative products that will be used for resilience planning and implementation for wildfire, flooding, climate change and extreme events, and planning, implementation, and monitoring of built and natural infrastructure projects. The North Coast is a severely economically disadvantaged region, home to a high number of Tribes and Tribal communities and has experienced over 25% of California's wildfires in the last five years, while representing only 12% of California's land mass. 3DEP program investments in this region have multiple long-term benefits for north coast ecosystems, economies, and communities.

Where they exist, regional consortia help manage and coordinate data acquisition, reduce data duplication, and effect better return on investments with the sharing of improved quality data.

Leveraging USGS National Map Liaisons and the National Map Liaison Network

The 3DEP program could boost non-Federal participation through well-established mechanisms. such as the USGS National Map Liaisons who are assigned to specific States and Territories in the U.S. Liaisons could support regional 3DEP data development and incorporation of elevation data from other sources. Many users still view elevation data as only a DSM and are missing the opportunity to use high-quality elevation data for multiple purposes including derived products.

The USGS National Map Liaisons have played a vital role in identifying State champions and some potential partners. With some increased funding or labor, the potential exists to build upon these established partnerships and reach a broader audience, spreading existing information. Formal cooperative agreements or memoranda of understanding with more groups and universities would increase program participation, possibly adding funding for higher density and/or more frequent coverage. Even though the 3DEP provides the framework

for elevation data acquisition, many users do not have a mechanism to acknowledge and share derived products through 3DEP as yet another opportunity to leverage others' good work. Their beneficial data and analyses need an exchange methodology to contribute derived products, applications, and tools to 3DEP as another source investment.

The Challenge of Differing Partner Budget Cycles

There is substantial preparatory work required for non-Federal participation. The BAA/DCA application and contracting timelines are short. Furthermore, Federal and non-Federal agency budget cycles often differ. These factors may limit the ability of non-Federal agencies to identify funding, develop and submit a proposal, and enter into contracts in time to meet BAA deadlines. This is often an issue with coordination of budget cycles, which non-Federal agencies have found to be problematic when partnership funding must be identified and committed on short notice.

Increased participation could add needed financial collaboration for more frequent or higher-density collections. Communicating and coordinating with potential partners in advance of planned projects would allow prospective partners to anticipate the schedule for planned data captures in advance in order to better synchronize them with their organizational budget cycles. USGS should consider approaches that may better balance provision of advance notice to potential community partners while maintaining flexibility to capitalize on funding opportunities as they arise.

Improving Communication of 3DEP non-Federal Benefits

The 3D Nation Study, referenced earlier, involved study participants from 45 Federal agencies, 56 States and territories, and 58 NGOs. Table 2 below breaks out the factors from the $13.5 billion in projected benefits. Non-Federal agencies are expected to receive 57% of future annual benefits from 3DEP should their requirements be met. Increased communication with non-Federal agencies could lend itself to increased overall program participation including participatory funding.

Table 2. Projected 3DEP Benefits Per 3D Nation Study, P12, Table 5

Organization Type	Total Reported Future Annual Benefits ($ billions)
Federal agencies	5.84
State, regional, county, local, and Tribal governments	7.68
Not-for-profit and private entities	0.04
Total	**13.56**

Working through Regional Consortia and Liaison networks can help to educate the community, agency representatives, and elected officials about the importance and multiple benefits of

investments in elevation data, including drawing attention to the significant cost savings associated with availability of 3DEP for better decision-making.

Improving Coordination with Federal Agencies

As elevation data becomes more widely collected across agencies, complying with the NLPA mandated FICC[23] will be important to improve coordination. Duties of this committee of designated members from multiple offices, led by the DOI in coordination with the Secretary of Commerce and the Secretary of Homeland Security, will oversee the planning, management, and coordination of the 3D Elevation Program and it will develop, implement, and periodically update a strategic plan. This governance body, when fully implemented, would aid in prioritizing competing collection demands including security and rapid response needs using its authority to have a periodically updated strategic plan with a detailed management plan. Developing mechanisms to receive interagency data while balancing security constraints in an information-sharing environment would provide derivative products for public consumption. Functional inter-agency coordination should include a variety of inputs, applications, and tools, adding new users across multiple platforms.

Many Federal agencies are identified on the USGS website as partners. Many Federal government organizations are recognized as users of elevation data, which is necessary for their operations, but they do not necessarily contribute to the data collections or to the resources needed. Utilizing a comprehensive list of Federal agency users[24] coupled with increased allocations from their budgets to support the acquisition and development of these information products would help to ensure this important program continues to support their operational workflows and business use cases.

Improving Partnerships with the Private Sector

While the USGS has been successful in partnership building[25], extensive efforts to reach out to key industry segments- such as infrastructure and transportation, agriculture, and broadband and telecom - have not resulted in funding partnerships. Partnerships to date have been largely governmental. The private sector uses the data extensively, yet the 3DEP program has not been able to directly attract private sector partnerships. In recent years, the USGS has engaged in P3 discussions with the NGAC and has worked with the GeoBuiz community to raise awareness and potential for the private sector to partner with 3DEP on data acquisition or technical development. New private investment approaches could help finance success for the goals of the next generation 3DEP.

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[23] PUBLIC LAW 116–323—JAN. 5, 2021, Section 5 (b)

[24] See Appendix F - Federal Agency MCAs (dewberry.com)

[25] Reference factsheets: Infrastructure - The 3D Elevation Program and America's infrastructure (usgs.gov), Precision Agriculture - The 3D elevation program - Precision agriculture and other farm practices (usgs.gov), broadband - 3D Elevation Program supports broadband internet access | U.S. Geological Survey (usgs.gov)).

CONCLUDING REMARKS

The Subcommittee has concluded through this assessment that 3DEP has successfully advanced its initial goal of full lidar coverage of the Nation, helping to address many of the requirements and benefits as described in the NEEA. The comprehensive management approach already established for the program and its array of partners from all national sectors has been a model for the Nation, which will only be enhanced through the establishment of an Interagency Coordinating Committee as directed by the NLPA.

3DEP has also been a catalyst for growth of the lidar services and equipment industry. It has effectively driven the advancement of private-sector technology, including tools for storing and processing lidar data. In addition, this program has delivered both tools for and approaches to storing, manipulating, and generating lidar-derived products and analytics.

Just as USGS should confidently advance on the goals of the current 3DEP to reach 100% coverage efficaciously, they will not miss any opportunity for further, substantive improvement in 3DEP quality, efficiencies, and capabilities to support a growing range of user needs. A 3DNTM draft plan is under development, which strongly promotes ongoing research, technology and application development, and a critical assessment of the existing and future program design. When finalized, this plan will position the program to respond to advances in sensor technology as well as potentially incorporating new types of data to meet current and future user needs.

This very successful public/private partnership will continue in the next generation of 3DEP.

RECOMMENDATIONS

OVERARCHING RECOMMENDATIONS

1. First and foremost, the subcommittee recommends that 3DEP “stay the course” to prioritize achievement of 100% national coverage as soon as practical.
2. The subcommittee recognizes that the USGS is not yet budgeted to address several of the recommendations provided below. However, given the significant projected return on investment discussed in this document, USGS should incorporate these recommendations into its design plans when additional funding is provided to achieve its future vision.

In addition, the subcommittee provides the following recommendations that may help both the planning process and the execution of the resulting programs:

TECHNICAL/TECHNOLOGY

3. USGS should collaborate with its contractors to identify elements of the validation process that can be performed by the contractors prior to delivery to USGS validation, in order to speed up the process and help reduce the current 18-24 month delivery

timeline. Furthermore, USGS should encourage research on the automation of processes such as qualify control (QC) of 3D point-cloud data.

4. The way work is performed and the expectations of the end-users are constantly changing. USGS and its Geospatial Products and Services Contracts (GPSC) contractors should continue their existing practice of being up-to-date on the latest technologies and products available for lidar data collection and processing. 3DNTM managers should remain open to new products to meet user needs.
5. USGS should leverage new and emerging processing standards and artificial intelligence/machine learning (AI/ML) techniques to streamline and future-proof 3DEP processing, e.g., OGC API-Processes, OGC API-EDR (Environmental Data Retrieval), OGC API-Discrete Global Grid Systems (DGGS).
6. USGS should consider participating in software development sprints to directly engage the technology development and user communities in testing, prototyping, and validating next-generation 3DEP capabilities.

PARTNERSHIPS

7. USGS should further leverage The National Map Liaison network to increase local and regional participation by exploring opportunities for partner organizations to act as "conveners" or "coordinators" across the country.
8. USGS has communicated widely and effectively on its activities and on the 3DEP program, but the need remains for further education. The Federal Interagency Coordinating Committee (FICC) and USGS should continue to apply effort to directly relate the utility of 3DEP data to key national priorities such as: the Nation's Infrastructure, climate resilience; planning for, mitigation of and response to disasters; and the management, distribution, and infrastructure of water.
9. The NGAC 3DEP Subcommittee understands that Congress has recognized the connection lidar and USGS 3DEP provide for the national broadband mapping efforts. To reduce the digital divide, all Federal agencies involved in broadband mapping, coverage, and the deployment of related infrastructure-- such as the Federal Communications Commission (FCC), National Telecommunications and Information Administration (NTIA), and Rural Utilities Services (RUS), among others—should fully leverage, participate, partner, and help to fund the 3DEP.
10. While USGS has been successful in partnership building, extensive efforts to reach out to key industry segments such as infrastructure and transportation, agriculture, and broadband and telecom, have not resulted in significant funding partnerships. USGS should continue to investigate and pursue private sector investment approaches that could help enable the goals of next generation 3DEP program.

PROGRAM ENHANCEMENTS/FUTURE PLANS

11. USGS and partners should embrace and implement the 3DEP Ecosystem concept as described in this report. That would allow for the import and integration of local acquisitions from agencies such as State Departments of Transportation (DOTs) with their statewide elevation data sets. The Ecosystem could provide a central location where users can find some level of authoritative data and share useful data that might not meet all the 3DEP specifications but supplies the quality and "fit for use" assessments provided by data producers. Data analysis tools and code could also be shared.
12. 3DEP data storage and dissemination are extremely important, especially as change detection from multiple collections over time becomes increasingly needed and should be fully funded.
13. 3DEP should fully document the 3DEP system architecture to identify key system components, processes, standards, and data formats necessary to ensure interoperability across partners and the broader community, and to enable more effective and efficient 3DEP evolution.
14. 3DEP should include a requirement to develop a seamless 1-meter digital elevation model (DEM) for derivation of hydrography from elevation data.
15. 3DEP should explore workflows and processes that may yield Analysis Ready Data (ARD) and Decision Ready Information (DRI) of value to the community based on key indicators.

STANDARDS

16. 3DEP should explore increasing representation and resources in relevant Standards Development Organizations (SDOs) such as those described in this report. Current levels of shared expertise and collaborative support are insufficient to properly influence standards development activities that support 3DEP operations and evolution.

GOVERNANCE

17. USGS should implement the design for the next generation of 3DEP described in the 3D National Topography Model Call for Action Part 2: Next Generation 3D Elevation Program ("the 3DNTM draft plan") due for publication by USGS later this year.
18. The Department of the Interior in coordination with the Departments of Commerce and Homeland Security and with the support of USGS should fully implement the governance process outlined in the NLPA.
19. FICC and FGDC leadership should ensure participation from a broad range of Federal agencies with a need for data delivered through the 3DEP program.

APPENDIX 1: SUBCOMMITTEE MEMBERSHIP

SECTOR	NAME	ORGANIZATION
State/Local Government	Mr. Gary Thompson (Subcommittee Chair)	Chief, North Carolina Geodetic Survey State of North Carolina
State/Local Government	Gale Blackmer, Ph.D. (Subcommittee Vice Chair)	State Geologist and Bureau Director Pennsylvania Geological Survey
State/Local Government	William Haneberg, Ph.D.	State Geologist & Director Kentucky Geological Survey
State/Local Government	Steven Steinberg, Ph.D.	Geographic Information Officer County of Los Angeles, California
Regional Government	Ms. Lynn Dupont	Principal Planner/GIS Manager New Orleans Regional Planning Commission
Research and Academic Institutions	David Maidment, Ph.D.	Hussein M. Alharthy Centennial Chair in Civil Engineering Emeritus University of Texas
Industry Standards Development Organizations	Mr. Mark Reichardt	Former President & CEO Open Geospatial Consortium
Private Sector	Stewart Walker, Ph.D.	Managing Editor LIDAR Magazine
Private Sector	Mr. Jim Van Rens	Senior Vice President Riegl USA Inc.
Non-Profit	Ms. Karen Gaffney	Co-Founder and CEO, West Coast Watershed
Tribal	Mr. Garet Couch	President National Tribal Geographic Information Support Center

2022-2023 NGAC Vice Chair Roberta Lenczowski also made significant contributions to this report.

APPENDIX 2: PREVIOUS NGAC REPORTS ON THE 3D ELEVATION PROGRAM

The NGAC has provided advice and recommendations on 3DEP through multiple reports and papers since the inception of the program in 2012. Highlights include the following:

- In 2012, the NGAC published a report titled "Toward a National Geospatial Strategy." One of the recommendations in the paper was to implement coordinated multi-agency, intergovernmental geospatial data initiatives. A key example included with the recommendation was 3DEP.
- In 2012, the NGAC published a report titled "Elevation Subcommittee Summary Report." This report was developed in response to FGDC requesting advice and recommendations on the NEEA and 3DEP. The report addressed several issues, including expanding coordination with Federal partners, increasing project size, communicating availability of Federal partners' plans and funding, coordinating funding for projects with State partners, and engaging with partners using 3DEP program data.
- In 2015, the NGAC published a paper titled "3D Elevation Program Data Acquisition Coordination." This report addressed the following question: "Given the new (3DEP) approach, what advice and/or recommendations does NGAC have for improving coordination and communication on 3DEP partnerships among community stakeholders?"
- In 2015, the NGAC produced a paper, "Comments on NAPA Report on FEMA Flood Mapping Program," which included the following recommendations:
    - NGAC endorsement of the recommendations in the National Academy of Public Administration's FEMA Flood Mapping report
    - NGAC recommendation that the FGDC community consider and take action on additional mechanisms described in the report of the National Academy of Public Administration (NAPA) report to facilitate coordination between FEMA and the 3DEP program.

  The paper also included a resolution endorsing NAPA's recommendation that the Office of Management and Budget should use the implementation plan of 3DEP for nationwide elevation data as a guide for the development of the President's annual budget.
- In 2016, the NGAC published a paper, "Addressing National Priorities through Geospatial Technologies," providing recommendations for the 2017 Presidential Transition. The paper provided information on geospatial technology and data, including overarching benefits, benefits to government operations, and benefits to the public. As part of its recommendations, the NGAC urged the Administration to fully implement 3DEP.
- In 2020, the NGAC's Public-Private Partnerships Subcommittee published a "Public-Private Partnership Use Case" report on 3DEP. The report included 3DEP background information, and addressed 3D lidar acquisition partnerships, how 3DEP works and why it works, and lessons learned from the program.

APPENDIX 3: 3DEP STANDARDS AND DATA FORMATS

Application of broadly adopted, open data formats and standards is critical to ease interoperability and to facilitate rapid mobilization of new capabilities across a growing variety of collection platforms and the broader 3DEP workflow that includes ingest and harmonization of data sets received from an array of partners and suppliers, data processing data management, and 3D elevation data distribution.

The following is a detailed list of existing, commonly used standards/data formats used across the community, many of which are implemented within 3DEP:

- http://www.usgs.gov/ngp-standards-and-specifications/lidar-base-specification-online: LBS provides a common base specification for data acquired through 3DEP.
- Cloud Optimized GeoTIFF A Cloud Optimized GeoTIFF (COG) is a GeoTIFF file with an internal organization that enables more efficient workflows in the cloud environment.
- LAS 1.4 LASer (LAS) file format supports point cloud data sets including those derived from Lidar and related sources. The standard is developed by ASPRS and has been adopted by the Open Geospatial Consortium (OGC) as a Community Standard. Version 1.5 is currently under development.
- HDF5 Hierarchical Data Format Version 5 (HDF5®) is a data model, a programming interface, and a storage model for keeping and managing data. It supports an unlimited variety of data types and is designed to be flexible and efficient for large and complex data. Developed by the HDF Group and now an OGC standard, this standard would be most useful as topographic and hydrographic information is integrated as part of the 3DNTM NextGen program.
- LAZ, a compressed form of LAS from the company rapidlasso GmbH (proprietary, but open-source)
- Cloud Optimized Point Cloud (which is based on LAZ) developed by Hobu, Inc. (proprietary)

Consideration should be given to additional existing and emerging data standards/formats that could be useful in improving / streamlining 3DEP operations and to support the incorporation of new capabilities. Examples include:

- OGC APIs including API-3D GeoVolumes, API-Coverages, API-Processes, API-EDR (Environmental Data Retrieval), API-Discrete Global Grid Systems (DGGS)
- Other OGC standards including, I3S, 3D Tiles
- National Imagery Transmission Format (NITF), MIL-STD- 2500 C

The GDA encourages the use of open standards “consistent with international standards to the maximum extent possible.” Further, OMB Circular A-119 cites preference for voluntary consensus open standards. There is interest and activity within the SDO community to transition the above-mentioned proprietary standards to open standards where possible, which would minimize the potential for issues related to intellectual property and unexpected and undesired unilateral change.

LIST OF ACRONYMS

3D	Three-dimensional
3DEP	3D Elevation Program
3DHP	3D Hydrology Program
3DNTM	3D National Topography Model (used also for Next Generation 3DEP)
AASG	Association of American State Geologists
API	Application Programming Interface
ARD	Analysis Ready Data
ASPRS	American Society for Photogrammetry and Remote Sensing
BAA	Broad Area Announcement
COG	Cloud Optimized GeoTIFF
CONUS	Continental (or Contiguous) United States
CPI	Consumer Price Index
DCA	Data Collaboration Announcement
DEM	Digital Elevation Model
DGGS	Discrete Global Grid Systems
DOT	Department of Transportation
DRI	Decision Ready Information
DSM	Digital Surface Model
DTM	Digital Terrain Model
EROS	Earth Resources Observation and Science Center
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FGDC	Federal Geographic Data Committee
FICC	Federal Interagency Coordinating Committee
FWL	Full Waveform Lidar
GDA	Geospatial Data Act
GNSS	Global Navigation Satellite System
GPSC	Geospatial Products and Services Contracts
HDF5	Hierarchical Data Format Version 5®
IDIQ	Indefinite Delivery, Indefinite Quantity Contract
IfSAR	Interferometric Synthetic Aperture Radar
IMU	Inertial Measurement Unit
IRA	Inflation Reduction Act
ISO	International Organization of Standards
LAS	LASer file format
LAZ	A compressed form of LAS
LBS	Lidar Base Specification
Lidar	Light Detection and Ranging
MAPPS	Management Association for Private Photogrammetric Surveyors

MMS	Mobile Mapping System
NAPA	National Academy of Public Administration
NCRP	North Coast Resource Partnership
NEEA	National Enhanced Elevation Assessment
NGAC	National Geospatial Advisory Committee
NGDA	National Geospatial Data Asset
NGO	Non-Governmental Organization
NGP	National Geospatial Program
NITF	National Imagery Transmission Format
NLPA	National Landslide Preparedness Act
NSDI	National Spatial Data Infrastructure
NSGIC	National States Geographic Information Council
NSPS	National Society of Professional Surveyors
NTIA	National Telecommunications and Information Administration
OGC	Open Geospatial Consortium
OMB	Office of Management and Budget
ORI	Orthorectified Radar Image
P3	Public-Private Partnerships
QC	Quality Control
QLs	Topographic Data Quality Levels
RUS	Rural Utilities Services
SAR	Synthetic Aperture Radar
SDOs	Standards Developing Organizations
SfM	Structure from Motion
TOP	The Opportunity Project
UAV	Unmanned Aerial Vehicle
US GEO	U.S. Geospatial Executives Organization
USGS	United States Geological Survey
USIEI	US Interagency Elevation Inventory