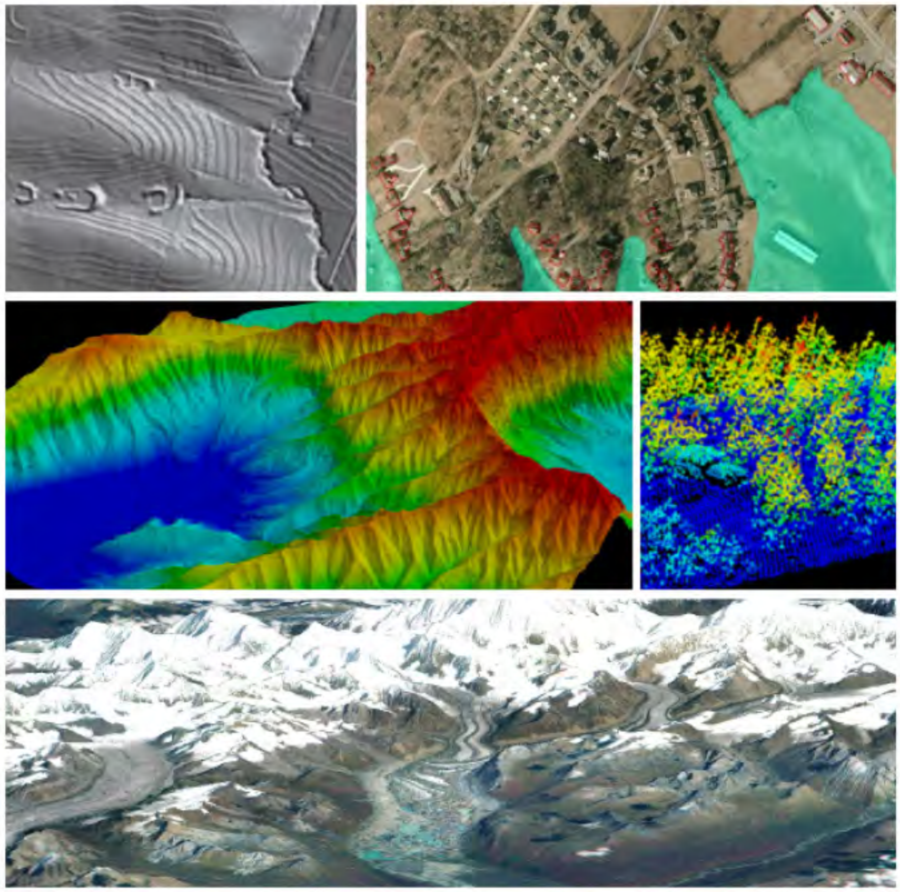
Dewberry



USGS

National Enhanced Elevation Assessment

Revised March 29, 2012

SUBMITTED BY:

Dewberry
8401 Arlington Boulevard
Fairfax, Virginia 22031-4666
703.849.0100

Table of Contents

1. Executive Summary

National Enhanced Elevation Assessment (NEEA)

The U.S. Geological Survey (USGS) and other members of the National Digital Elevation Program (NDEP) sponsored the first-ever national assessment to document Business Use requirements for and benefits of national enhanced elevation data that would significantly expand national elevation data availability, quality and usability. The goal of the assessment was to develop and refine requirements for a national program and to identify program implementation alternatives, costs and benefits for meeting priority national elevation data needs. The assessment quantifies answers to three key questions.

1. Is it more cost effective for the government to manage these activities within the context of a national program?
2. Are there additional national or agency benefits derived from such a strategy?
3. What does the optimized program look like?

The assessment results provide significant evidence that an enhanced national elevation program could provide conservatively-estimated net benefits between $116M/year and $620M/year and Benefit/Cost Ratios between 4.3 to 1 and 4.9 to 1, depending upon options implemented.

The National Enhanced Elevation Assessment (NEEA) was performed by Dewberry under contract to the USGS to provide technical input and analysis to the Government concerning alternatives and strategies for better meeting the Nation's needs for enhanced elevation data. This report is an intermediate work product and does not make directed recommendations or reflect Government positions related to possible future program preferences or expectations.

Background

OMB Circular A-16, "Coordination of Geographic Information and Related Spatial Data Activities," designates the USGS as the lead agency for terrestrial elevation data. For most of the past century, Americans have relied upon paper topographic quadrangle maps from USGS to visualize the 3-D shape of the topography by human interpretation of contour lines manually compiled by labor-intensive photogrammetric processes. Since 2003, the USGS has been incorporating high-resolution elevation data derived from Light Detection and Ranging (LiDAR) into the National Elevation Dataset (NED), a seamless dataset containing regularly spaced elevation points and initially populated from scanned topographic maps. Considering publically available data with no overlaps, approximately 28 percent of the lower 49 states have LiDAR data; and at the current rate of 2 to 3 percent per year, it could take 35 years to complete nationwide coverage – long past the time when updated LiDAR would be required.

The NED, serving as the elevation layer of *The National Map*, provides gridded Digital Elevation Models (DEMs) of the bare-earth terrain to the public at three different *post spacings*, based on arc-seconds of latitude and longitude to include:

1. 1-arc-second DEMs have elevation *posts* approximately 30 meters apart;
2. 1/3-arc-second DEMs have elevation *posts* approximately 10 meters apart; and
3. 1/9-arc-second DEMs have elevation *posts* approximately 3 meters apart.

The 1-arc-second and 1/3-arc-second DEMs, now complete nationwide, are primarily produced from the paper topographic quadrangle maps that are 30 to 50 years old. Only a small portion of the country is covered with 1/9-arc-second DEMs produced from newer data, primarily LiDAR, but demand is rising for 1/27-arc-second data that have elevation *posts* approximately 1 meter apart as derived from high-accuracy and high-resolution LiDAR data. The best that USGS can currently do to satisfy these needs is to produce 1/9-arc-second DEMs for the NED and serve LiDAR point cloud data to the public as data become available from federal, state or local mapping programs.

Federal agencies including the USGS, Natural Resources Conservation Service (NRCS), National Oceanic and Atmospheric Administration (NOAA), National Geospatial-Intelligence Agency (NGA), Federal Emergency Management Agency (FEMA), and the U.S. Army Corps of Engineers (USACE) are making significant investments in LiDAR data collection programs to support key missions. In addition, several states have either completed statewide projects or are actively planning LiDAR programs. Elevation data collection projects are usually coordinated with multiple funding organizations. Data acquisition projects are limited to the geographic areas where funding and common requirements coincide, and data consistency varies from project to project. These limitations can compromise any analysis over large geographic areas or any place an operational need crosses project boundaries. As LiDAR technology has gained widespread acceptance, and more organizations are considering acquisition programs, the need for coordination among the LiDAR user community has increased.

To develop a plan for addressing unmet national elevation needs, the USGS worked with partners (NGA, FEMA, NRCS, NOAA, and others) to sponsor this assessment to identify *mission-critical*[1] needs for elevation data at all levels of government as well as other organizations (not-for-profit and private companies). Dewberry, a company specializing in elevation data and services, conducted major portions of this assessment for the USGS. The assessment follows several other key reports that identified requirements for nationwide LiDAR data and the value of partnerships to fulfill these needs.

Two reports from the National Research Council (NRC), *Elevation Data for Floodplain Mapping*, published in 2007, and *Mapping the Zone: Improving Flood Map Accuracy*, published in 2009, concluded that: (1) accurate topographic data are the most important factor in flood risk mapping and determination of water surface elevations, base flood elevations, and the extent of flooding; (2) America needs nationwide LiDAR with applications well beyond FEMA’s requirements for floodplain mapping; and (3) FEMA should increase its collaboration with other federal, state and local government agencies to acquire high-resolution, high-accuracy topographic and bathymetric data throughout the nation.

A report from the Congressional Research Service (CRS), *Geospatial Information and Geographic Information Systems (GIS): Current Issues and Future Challenges*, published in 2010, references the 2009 NRC report. The CRS emphasized the critical importance of geospatial data at all levels of government and the private sector – using elevation data for FEMA and others as a prime example of how

[1] Throughout this assessment, *mission-critical* was defined as “indispensable for mission accomplishment and/or essential for effective/efficient operations in accomplishing the core mission ofthe organization.”

government agencies need to work together and facilitate partnerships to develop standard products to satisfy common needs.

Assessment Procedures

For the ease of data collection and analysis, 27 major Business Uses (Table 1.1), five enhanced elevation data Quality Levels (QLs) (2-3%) and five update frequency levels were pre-defined. Dewberry then worked with 34 Federal agencies and 13 other private and non-profit organizations while USGS worked with all 50 states and U.S. territories, 11 tribal governments, and a sample of local governments (57 counties, 17 cities and towns, and 22 regional governments). Business Uses requiring enhanced elevation data, and expected benefits of a national program, were documented.

Table 1.1. The 27 pre-defined Business Use (BU) numbers and names

1. Natural resources conservation	15. Sea level rise and subsidence
2. Water supply and quality	16. Wildfire management, planning and response
3. River & stream resource management	17. Homeland security, law enforcement, and disaster response
4. Coastal zone management	18. Land navigation and safety
5. Forest resources management	19. Marine navigation and safety
6. Rangeland management	20. Aviation navigation and safety
7. Wildlife and habitat management	21. Infrastructure and construction management
8. Agriculture and precision farming	22. Urban and regional planning
9. Geologic resource assessment and hazard mitigation	23. Health and human services
10. Resource mining	24. Real estate/banking/mortgage/insurance
11. Renewable energy resources	25. Education K-12 and beyond
12. Oil and gas resources	26. Recreation
13. Cultural resources preservation and management	27. Telecommunications
14. Flood risk management	

The five pre-defined Quality Levels of topographic data are summarized in Table 1.2, and the five update frequencies were identified as: (1) annual updates; (2) every 2-3 years; (3) every 4-5 years; (4) every 6-10 years; and (5) greater than 10 years, assumed to be 15 years. Respondents could also specify event-driven requirements not regularly scheduled.

Table 1.2. The five pre-defined topographic data Quality Levels (QLs)

Elevation Quality Levels (QL)	Source	Horizontal Resolution Terms			Vertical Accuracy Terms	
		Point Density	Nominal Pulse Spacing (NPS)	DEM Post Spacing	Vertical RMSEz	Equivalent Contour Accuracy
QL 1	LiDAR	8 pts/m^2	0.35 m	1/27 arc-sec ~1 meter	9.25 cm	1-ft
QL 2	LiDAR	2 pts/m^2	0.7 m	1/27 arc-sec ~1 meter	9.25 cm	1-ft
QL 3	LiDAR	1 – 0.25 pts/m^2	1 – 2 m	1/9 arc-sec ~3 meters	≤18.5 cm	2-ft
QL 4	Imagery	0.04 pts/m^2	5 m	1/3 arc-sec ~10 meters	46.3 cm – 139 cm	5 – 15 ft
QL 5	IFSAR	0.04 pts/m^2	5 m	1/3 arc-sec ~10 meters	92.7 cm – 185 cm	10 – 20 ft

As summarized in Table 1.2, each of the five designated topographic data Quality Levels is considered "enhanced" because each is superior in one way or another to the current patchwork of data in the NED, summarized in Appendix A.

All organizations identified key Functional Activities (FAs), described in their own words, with *mission-critical* requirements for enhanced elevation data, along with their elevation data requirements by Quality Levels, update frequencies, and geographic areas. Each Functional Activity was linked to the Business Use that was most similar to the described activity. These data were collected by an on-line Questionnaire, followed by an Interview/Workshop Process, and finalized with a Validation Process that resulted in the formal documentation of each organization's requirements and benefits.

Enhanced elevation data were identified as *mission-critical* for 602 Functional Activities (FAs), including 104 federal FAs, 329 state FAs, 144 local and tribal FAs, and 25 FAs from nongovernmental organizations including private companies. Although time and cost savings were identified as "major," annual cost benefits could not be estimated for over half of the Functional Activities.

Of Functional Activities that did estimate annual cost benefits, the conservatively-estimated annual benefits of enhanced elevation data total $1.2 billion/year.

Detailed analyses of understated and emerging benefits yielded potential benefits of $13.0 billion/year in future years when new technologies are implemented.

Only the conservative dollar benefits were used in the Benefit Cost Analyses, but not all of these benefits are achieved for any of the scenarios evaluated because not every Functional Activity receives exactly the Quality Level and update frequency required when maximizing Net Benefits and/or Benefit/Cost ratios in Benefit Cost Analyses or when normalizing Quality Levels or update frequencies for consistency.

All of these data were entered by Dewberry into a master geodatabase. Appendix B documents 104 Functional Activities from federal agencies. Appendix C documents 329 Functional Activities from states and U.S. territories plus 144 Functional Activities from local and tribal governments within each state. Appendix D documents 25 Functional Activities from one not-for-profit and 12 private companies. USGS also performed an inventory of existing elevation datasets available in the public domain.

Dewberry then aggregated and analyzed all elevation data requirements and benefits for each Functional Activity and Business Use, summarized at Appendix E. Each Functional Activity was summarized for its *mission-critical* elevation data requirements by Quality Level and update frequency; and its tangible and intangible benefits to include annual dollar benefits for use in the Benefit Cost Analyses. For nearly all of the 27 Business Uses, Dewberry believes the reported dollar benefits were understated for reasons explained at Appendix E which estimates higher potential benefits.

As shown at Table 1.3, the conservative benefits total $1.2 billion/year and the potential benefits total $13.0 billion/year. However, not all of these benefits will be achieved if users receive poorer Quality Level data or update frequencies than optimally required for each Functional Activity.

Only the conservative benefits were used in Dewberry's Benefit Cost Analyses. Table 1.3 compares the conservatively-estimated benefits that seem to be significantly understated, with potential future benefits that are much higher but may still be understated. Table 1.3, which was ranked by conservative benefits, contrasts conservative and potential benefits. State requirements and benefits vary widely in terms of data quality and benefits. For example, four states specified requirements for QL1 LiDAR and other states specified QL2 or QL3 LiDAR. In addition, North Carolina reported significantly higher benefits for coastal flood risk management than did other coastal states, and some states significantly underestimated or were unable to assign any benefits at all for flood risk management.

Table 1.3. Estimated Annual Dollar Benefits, by Business Use, from Enhanced Elevation Data

BU#	BU Name	Enhanced Elevation Data Annual Benefits	
		Conservative Benefits	Potential Benefits
14	Flood Risk Management	$294.706M	$501.576M
21	Infrastructure and Construction Management	$206.212M	$941.951M
1	Natural Resources Conservation	$159.225M	$335.152M
8	Agriculture and Precision Farming	$122.330M	$2,011.330M
2	Water Supply and Quality	$85.288M	$156.351M
16	Wildfire Management, Planning and Response	$75.700M	$158.950M
9	Geologic Resource Assessment and Hazard Mitigation	$51.750M	$1,066.750M
5	Forest Resources Management	$43.949M	$61.655M
3	River and Stream Resource Management	$38.422M	$86.582M
20	Aviation Navigation and Safety	$35.000M	$56.000M
4	Coastal Zone Management	$23.785M	$41.740M
11	Renewable Energy Resources	$10.050M	$100.050M
12	Oil and Gas Resources	$10.000M	$100.000M
17	Homeland Security, Law Enforcement, Disaster Response	$9.975M	$126.469M
15	Sea Level Rise and Subsidence	$5.780M	$21.660M
22	Urban and Regional Planning	$4.197M	$68.569M
10	Resource Mining	$1.686M	$4.864M
7	Wildlife and Habitat Management	$1.510M	$4.020M
25	Education K-12 and Beyond	$0.264M	$2.264M
18	Land Navigation and Safety	$0.191M	$7,124.875M
27	Telecommunications	$0.185M	$1.850M
26	Recreation	$0.050M	$0.050M
13	Cultural Resources Preservation and Management	$0.000M	$7.000M
23	Health and Human Services	$0.000M	$1.000M
19	Marine Navigation and Safety	$0.000M	$0.000M
24	Real Estate, Banking, Mortgage, Insurance	$0.000M	$0.000M
6	Rangeland Management	$0.000M	$0.000M
	Total Estimated Annual Dollar Benefits	**$1,180.224M**	**$12,980.707M**

Benefit Cost Analyses

For the 48 conterminous states, USGS provided average cost estimates by Quality Level from its Geospatial Products and Services Contract 2 (GPSC2) contractors for Quality Levels 1 through 4. These estimates, in 2011 dollars, are in column B in Table 1.4 below. Columns C and D include the 15 percent estimated costs of QA/QC to include the survey of QA/QC checkpoints. Column E assumes 5 percent for USGS to manage the acquisition and processing of data. Column F includes the total cost per square mile used in the Benefit Cost Analyses. Dewberry provided cost estimates for Quality Level 5 IFSAR (Interferometric Synthetic Aperture Radar) in Alaska ($94.50/mi^2) and reduced costs for Quality Level 5 IFSAR in the other 49 states ($80/mi^2) where acquisition costs are estimated to be about 18 percent lower because of improved access to suitable airports and facilities; future costs are also dependent on the changing price of aviation fuel and the Consumer Price Index (CPI). All costs assume that the same Quality Level of elevation data is acquired in the most efficient manner for entire 1-degree cells (1°

latitude by 1° longitude). Most elevation data today are acquired in a less efficient manner, i.e., smaller, irregularly-shaped areas that cost more per square mile.

Table 1.4. Estimation of Costs per Square Mile for the Five Quality Levels

A	B	C	D	E	F
Quality Level	**$/mi^2**	**QA/QC**	**Subtotal**	**USGS**	**Total $/mi^2**
QL1 LiDAR (48 states)	$453.25	$67.99	$521.24	$26.06	$547.30
QL2 LiDAR (48 states)	$277.00	$41.55	$318.55	$15.93	$334.48
QL3 LiDAR (48 states)	$209.25	$31.39	$240.64	$12.03	$252.67
QL4 1-m Image DEM (48 states)	$134.00	$20.10	$154.10	$7.71	$161.81
QL5 IFSAR (Alaska)	$90.00	Included	$90.00	$4.50	$94.50
QL5 IFSAR (49 states)					$80.00

Recognizing that benefits are degraded if users do not receive the Quality Level and update frequency required, Dewberry developed a procedure for degrading annual dollar benefits with reduced *value multipliers*. Table 1.5 shows how the benefits *value multiplier* is decreased for a Functional Activity that has the most demanding requirement (QL1 LiDAR with annual updates) and receives something less than that (shown in the other 24 alternatives). For other less-demanding requirements, the *value multiplier* is 1.0 (full benefit value) if the Quality Level and update frequency is equal to or better than required, but decreased by half for every column to the right for Quality Level and for every row beneath for update frequency.

Table 1.5. Benefits *Value Multipliers* with Poorer Quality Level and Update Frequency

Update Frequency	QL1 LiDAR	QL2 LiDAR	QL3 LiDAR	QL4 DEM	QL5 IFSAR
Annually	1	1/2	1/4	1/8	1/16
2-3 years	1/2	1/4	1/8	1/16	1/32
4-5 years	1/4	1/8	1/16	1/32	1/64
6-10 years	1/8	1/16	1/32	1/64	1/128
>10 years	1/16	1/32	1/64	1/128	1/256

Most-Requested Quality Levels and Update Frequencies

Nearly half (49.13%) of the managers from federal, state and nongovernmental organizations[2] were unable to estimate their benefits even though they specified *mission-critical* requirements for enhanced elevation data that would provide major (but unknown) time/cost savings and/or major (but unknown) benefits to their customers. Therefore, nearly half of the Functional Activities did not influence the Benefit Cost Analyses summarized above in Table 1.3. To give some weight to all requirements, with or without estimated dollar benefits, Dewberry determined the most-requested Quality Levels and update frequencies for each 1-degree cell and considered these requirements in development of alternative program implementation scenarios for which Benefit Cost Analyses were performed.

[2] Throughout this report, all references to "nongovernmental organizations" refer to not-for-profit organizations and for-profit companies for which mission-critical Functional Activity requirements and benefits are documented in Appendix D.

Appendix F includes eight maps (see Figures F.1 through F.8) showing the most-requested Quality Levels and update frequencies: (1) for federal government agencies only, (2) for states only, (3) for nongovernmental organizations (not-for-profit/private companies) only, and (4) for all combined. Nationwide, the most-requested Quality Level is QL3 LiDAR, followed by QL2 and QL1 LiDAR; and the most-requested update frequency is 6-10 years. Note that while QL3 LiDAR collected on a 6-10 year cycle is most frequently requested, it neither represents the highest Benefit/Cost Ratio nor the highest net benefit.

Highest Net Benefits

Two widely used methods for performing Benefit Cost Analyses are: (1) Net Benefits (NB) where costs are subtracted from the benefits (NB = benefits minus costs); and (2) Benefit/Cost Ratio (B/C Ratio) where the benefits are divided by the costs (B/C Ratio = benefits/costs). Dewberry used the master geodatabase to optimize Net Benefits, but also computed the B/C Ratio for each option.

Note: Even though the Quality Level and update frequency were selected in the following options to optimize federal benefits, state benefits, and nongovernmental benefits, the total benefits include all the requirements for the other sectors that are met under these scenarios. This section of the report summarizes key statistics when considering data costs only; Information Technology (IT) infrastructure costs will be added later in this analysis when addressing lifecycle costs and benefits.

Federal Agencies: To achieve the highest net benefits for federal agencies only, Dewberry determined the optimal Quality Level and update frequency for each 1-degree cell (see Figures F.9 and F.10 in Appendix F). The major federal statistics (for data only) are as follows.

Total Costs: $124M/year	**Total Benefits: $252M/year**
Benefit/Cost Ratio: 2.031	**Net Benefits: $128M/year**

State Governments: To achieve the highest net benefits for state governments only, Dewberry determined the optimal Quality Level and update frequency for each 1-degree cell (see Figures F.11 and F.12 in Appendix F). The major state statistics (for data only) are as follows:

Total Costs: $105M/year	**Total Benefits: $506M/year**
Benefit/Cost Ratio: 4.82	**Net Benefits: $401M/year**

Nongovernmental Users (not-for-profit and private companies): To achieve the highest net benefits for nongovernmental users only, Dewberry determined the optimal Quality Level and update frequency for each 1-degree cell (see Figures F.13 and F.14 in Appendix F). The major nongovernmental statistics (for data only) are as follows:

Total Costs: $60M/year	**Total Benefits: $133M/year**
Benefit/Cost Ratio: 2.206	**Net Benefits: $73M/year**

Combined Federal/State/Nongovernmental: To achieve the highest net benefits for combined federal and state governments plus nongovernmental users, Dewberry determined the optimal Quality Level and update frequency for each 1-degree cell (see Figures F.15 and F.16 in Appendix F). The major combined statistics (for data only) are as follows:

Total Costs: $213M/year	Total Benefits: $1,008M/year
Benefit/Cost Ratio: 4.728	Net Benefits: $795M/year

The Benefit Cost Analyses demonstrate the synergy achieved if sectors work together to meet their common needs. Table 1.6 shows that if the federal government, state governments, and nongovernmental organizations work as independent groups, their subtotal aggregate annual costs would be higher ($289M), their aggregate benefits would be lower ($891M), and the annual net benefits ($602M) would be lower (yellow), than if the groups work in combination to optimize the overall benefit-cost model (green). The Combined Highest Net Benefits option will subsequently be analyzed as Scenario 4 later in this report.

Table 1.6. The combined (synergistic) net benefits exceed the individual federal, state and nongovernmental benefits

User Group	Annual Costs	Annual Benefits	Annual Net Benefits	B/C Ratio
Federal highest net benefits	$124M/year	$252M/year	$128M/year	2.031
State highest net benefits	$105M/year	$506M/year	$401M/year	4.820
Nongov. highest net benefits	$60M/year	$133M/year	$73M/year	2.206
Subtotal highest net benefits	$289M/year	$891M/year	$602M/year	3.079
Combined highest net benefits	$213M/year	$1,008M/year	$795M/year	4.728

Comparison of Uniform Options for 48 Conterminous States

Dewberry used the power of the geodatabase to evaluate all 25 options (five update frequencies for each Quality Level) for collecting elevation data (Table 1.7.) Each option would result in a uniform Quality Level and a uniform update frequency for the 48 conterminous states, excluding Alaska, Hawaii and U.S. territories. For each option, the table shows annual total data costs, annual total benefits, annual net benefits (negative net benefits for red numbers in parentheses) and B/C Ratios. The five colors in this table match those used in all maps in this report that show Quality Levels.

Table 1.7. Comparison of Benefit/Cost Ratios and Net Benefits for all 25 Quality Level and Update Frequency Options

Option #	Quality Level	Update Frequency	Annual Total Costs	Annual Total Benefits	Benefit/Cost Ratio	Net Benefits (Benefits - Costs)
1	1	Annual	$1,646M	$1,111M	0.674	($536M)
2	1	2-3 years	$659M	$1,110M	1.685	$451M
3	1	4-5 years	$366M	$1,066M	2.914	$700M
4	1	6-10 years	$206M	$800M	3.887	$594M
5	1	>10 years	$110M	$403M	3.671	$293M
6	2	Annual	$1,006M	$923M	0.917	($84M)
7	2	2-3 years	$402M	$922M	2.291	$520M
8	2	4-5 years	$224M	$888M	3.970	$664M
9	2	6-10 years	$126M	$674M	5.356	$548M
10	2	>10 years	$67M	$339M	5.049	$272M
11	3	Annual	$760M	$697M	0.917	($63M)
12	3	2-3 years	$304M	$696M	2.291	$392M
13	3	4-5 years	$169M	$673M	3.983	$504M
14	3	6-10 years	$95M	$501M	5.278	$406M
15	3	>10 years	$51M	$252M	4.970	$201M

16	4	Annual	$487M	$361M	0.741	($126M)
17	4	2-3 years	$195M	$360M	1.851	$166M
18	4	4-5 years	$108M	$346M	3.198	$238M
19	4	6-10 years	$61M	$256M	4.204	$195M
20	4	>10 years	$32M	$129M	3.962	$96M
21	5	Annual	$241M	$190M	0.788	($51M)
22	5	2-3 years	$96M	$190M	1.970	$93M
23	5	4-5 years	$53M	$180M	3.365	$126M
24	5	6-10 years	$30M	$131M	4.369	$101M
25	5	>10 years	$16M	$66M	4.118	$50M

Although Option 3 (LiDAR QL1, 4-5 year update frequency) has the highest Net Benefits, Option 9 (LiDAR QL2, 6-10 year update frequency) provides the best B/C Ratio (5.356) with annual Net Benefits of $548M. Therefore Option 9 would provide the "biggest bang for the buck" if a uniform Quality Level and update frequency option is desired for the 48 conterminous states.

Table 1.7 does not imply that alternatives are limited to uniform data Quality Levels for the 48 conterminous states, and certainly not for all 50 states and U.S. territories. For example, Alaska has many requirements for LiDAR (as documented in Appendix C), but IFSAR provides a more-realistic and achievable statewide solution for Alaska because IFSAR maps through clouds and fog that would make LiDAR unachievable or unaffordable throughout much of that state. LiDAR is still appropriate for smaller areas in Alaska when justified on a case-by-case basis. Furthermore, LiDAR costs for Hawaii and the U.S. territories, all islands, will be higher than average estimates in Table 1.4 for the 48 conterminous states.

National Program Implementation Scenarios

Approximately 28.4 percent of the combined area of the lower 49 states plus Washington D.C. is covered by publically available LiDAR data, ranging from QL1 to QL4;15.2% of Alaska has QL5 IFSAR data. Most existing data are of a lower QL than required by the majority of federal, state and nongovernmental Functional Activities identified in this assessment. Table 1.8 identifies the percent, by quality level, of the lower 49 states (plus D.C.) that is covered by publically available LiDAR data.

Table 1.8. Summary of Public Domain LiDAR Data

LiDAR Data Quality Level (QL)	Square Miles of Data Over the Lower 49 States + D.C.	Percent Coverage of the Area of the Lower 49 States + D.C.
QL1 LiDAR	27,912 mi^2	0.9%
QL2 LiDAR	22,160 mi^2	0.7%
QL3 LiDAR	728,103 mi^2	23.7%
QL4 LiDAR	94,100 mi^2	3.1%
Totals	**872,276** mi^2	**28.4%**

Although not included in this table, some QL4 data are also available from photogrammetry, and small areas of Alaska have QL3 LiDAR data. Other elevation datasets are proprietary and not publically available.

The current state of the Nation's elevation data collection efforts and data availability (the "status quo") can be characterized as follows:

1. Federal, state and local agencies seek funding partners for data acquisition.

2. Data collection partnerships often occur on an ad-hoc basis as funding and common interests allow, but not as part of a directed, pre-planned national program with an expected completion date.
3. Federal, state and local agencies set schedules and Quality Level (QL) requirements, manage contracts, and perform their own quality assurance/quality control (QA/QC) or contract for independent third-party QA/QC.
4. Federal, state, and local agencies submit data to USGS for the NED and/or the Center for LiDAR Information, Coordination and Knowledge (CLICK); this does not always happen.
5. Commercial vendors sell data without distribution restrictions, or as licensed products (e.g., Interferometric Synthetic Aperture Radar (IFSAR) datasets)

The current or "status quo" state of LiDAR collection is widely considered to be unacceptable. At the current data collection rate it would take 35 years to collect nationwide data. It is also likely that portions of the country would remain unmapped while others would be remapped several times over.

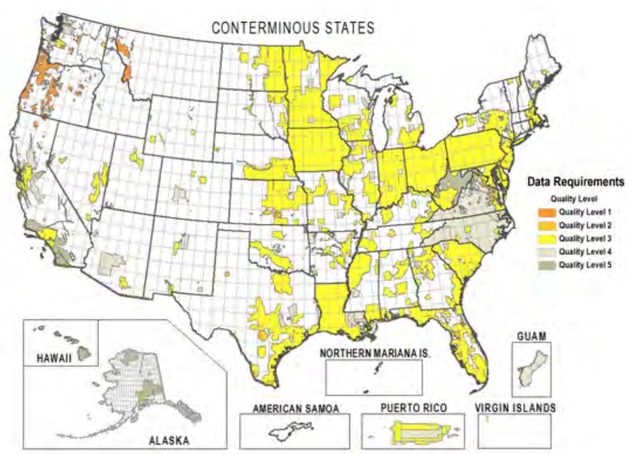


Figure 1.1. Status quo, enhanced elevation data inventory including projects in progress and funded projects.

Figure 1.1 maps the location of the various Quality Levels of enhanced elevation data, mostly acquired since 1998. Although it was the first to obtain statewide LiDAR, North Carolina is shown in Figure 1.1 as having QL4 data because the LiDAR vertical accuracy and horizontal resolution are poorer than specified for QL3 LiDAR in Table 1.2.

In recent years, enhanced elevation data have been added to the inventory at an average rate of approximately 4 percent per year; however, this is not the norm because a significant percentage of this increase resulted from American Recovery and Reinvestment Act (ARRA) funding which is not continuing. Even if the status quo were to provide complete coverage in 35 years, that would clearly be inadequate to meet the many federal, state and nongovernmental user requirements for enhanced elevation data at a 6-10 year update frequency.

As alternatives to the status quo, based on all of the Benefit Cost Analyses performed on the data collected for the NEEA, four primary National Program Implementation Scenarios were developed and analyzed by Dewberry. All four scenarios include QL5 IFSAR for Alaska (where LiDAR has technical challenges due to cloud cover and fog, and is more difficult to justify in benefit cost analyses except in populated areas). Whereas the status quo scenario is largely decentralized (characterized by opportunistic data collection partnerships) the following National Program Implementation Scenarios are partially or fully centralized. Each program scenario would include "buy up" options should other organizations find it necessary to acquire higher quality data.

- Scenario 1 – QL3 LiDAR with 25-year acquisition period: the lowest-cost alternative that would yield consistent QL3 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska over a 25-year acquisition period for all areas not previously mapped with QL3 LiDAR data or better.
- Scenario 2 – Mixed QL1/2/3 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska with 8-year acquisition period: a medium cost alternative that best satisfies federal requirements and provides the best federal net benefits. Many users were unable to provide quantified dollar benefits for their Functional Activities. This is the only scenario that uses the most-requested Quality Level requirements as a weighting factor (in addition to dollar benefits) in computing the optimal QL and update frequency.
- Scenario 3 – QL2 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska with 8-year acquisition period: a medium cost alternative that would yield QL2 LiDAR uniformly over the 49 states and U.S. territories.
- Scenario 4 – Mixed QL1/2/3 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska with 8-year acquisition period: the alternative that collectively optimizes the combined benefits of federal/state/nongovernmental requirements, and yields the highest combined net benefits (at the highest cost).

These four primary implementation scenarios are based on acquisition periods of 25 years, 8 years, 8 years, and 8 years, respectively. In addition, four alternative implementation scenarios (1A-4A), corresponding to each of the four primary scenarios, were computed based on 15-year acquisition periods. The alternative scenarios use the same Quality Levels per 1-degree cell as the primary scenarios. The four primary and four alternative implementation scenarios analyzed in this report are derived from the results of Benefit Cost Analyses described in Appendix F. All eight scenarios would lead to national data coverage, provide a positive return on investment (ROI), and provide flexibility in terms of state and local "buy ups" to increase data quality or modify the data collection schedule.

The following paragraphs define three terms used above in the context of data collection efforts:

- A "Decentralized" program describes the opportunistic data collection programs in place today. The status quo is not nationally directed with respect to geographic coverage, quality, schedule or who participates in data collection activities. Projects are characteristically independently planned and completed where and when interests and funding allow, at various levels of contribution, using a variety of contracts and specifications, by some organizations having capabilities to manage a project and others not having these capabilities.
- A "Fully centralized" program would involve a single entity (presumably a federal agency) that receives full funding and has the responsibility to implement a national program of agreed-upon data quality and collection frequency. The federal government would consider a full spectrum of national requirements to implement such a program. Fully centralized would result in the most consistent data and likely the lowest cost data, given the expected regular collection and economies of scale in contract negotiations. The states or other partners would have less influence on all aspects of the program.

- "Partly centralized" is a partnership model where contributors share control of priorities affecting data quality, collection schedules and coverage areas. This would likely involve greater data variation, reduced consistency, and in some cases higher costs per square mile. Such a program could be less efficient but would lower the cost to any one partnership entity. Program priorities would be more focused on meeting partnership needs.

All program scenarios considered for this assessment are at least partly centralized. Dewberry assumes that USGS, because of its OMB Circular A-16 responsibilities, would manage elevation data acquisition, to include Quality Level specifications, scheduling, contracting, QA/QC, and creation of basic derivative products. All data would be centrally archived and disseminated, to include a basic suite of derivative products. Partners could "buy-up" to increase the Quality Level or update frequency of the data collected if they would contribute the additional cost it would take to acquire the data over and above the costs of the programmed data acquisition. Partners and/or users would be free to create and distribute additional derivative products based on their program and/or project requirements.

Scenario Common Advantages

All eight implementation scenarios have common advantages compared with the status quo:

1. A centralized or partly centralized National Enhanced Elevation Program makes the most sense in terms of contracting, continuity, specification alignment, and adherence to uniform acceptance criteria; resulting products are more likely to be consistent and compatible with adjoining elevation datasets, have good metadata, and be acceptable for a national program.
2. Acquisition of data and delivery of products to the USGS *LiDAR Guidelines and Base Specifications*, v13 (see Appendix I), or updates thereto, assures consistent, high-quality elevation data whereas acquisition of data to diverse alternative specifications often results in lower-quality data that may not be accepted for inclusion in a national program for public distribution.
3. A nationwide collection schedule would be developed and published so users know when and where areas are planned to be collected over a known acquisition cycle. If this Quality Level or acquisition schedule does not meet user requirements, they can "buy-up" to meet their needs.
4. Assuming the LiDAR and IFSAR data are systematically acquired in full 1-degree cells, the costs per square mile will be considerably lower than the higher costs typically paid under the status quo for smaller, irregularly-shaped areas at different Quality Levels.
5. The large-scale acquisition program would be managed by elevation data experts who are well versed in LiDAR and IFSAR data specifications, contracting requirements, and QA/QC procedures and requirements.
6. Users would have a 1-stop, reliable source of high-accuracy, high-resolution elevation data rather than researching multiple sources to determine the best available data.
7. Users would be able to more easily discover and obtain enhanced elevation data; they would know what Quality Level specifications, age, acquisition period, and derivative products to expect.
8. Consistent data standards nationwide would facilitate the development of applications software based on known data accuracy and density parameters.

9. Under any of the major scenarios, nationwide coverage of enhanced elevation data that are uniform and/or consistent in terms of data acquisition methodology, Quality Level, age, update frequency, QA/QC, metadata, and derivative products would generally be assured by the end of the first-pass collection cycle.
10. With all major scenarios, nationwide enhanced elevation data is expected to be in the public domain in concert with current distribution practices for the National Elevation Dataset.

Scenario Common Disadvantages / Challenges

All eight implementation scenarios also have common challenges compared with the status quo:

1. All eight scenarios require some level of new and stable funding.
2. For all scenarios, existing IT infrastructure would need to be upgraded to improve reliability and scaled to handle larger volumes of data and new services to users.
3. Centralized programs may cause state and local users to assume this is solely a federal responsibility and thereby reduce their own efforts to promote needed funding partnerships.

Scenario 1 – Uniform QL3 LiDAR, 25-year Acquisition Period

As shown in Figure 1.2, under Scenario 1, uniform QL3 LiDAR would be acquired over a 25-year acquisition period for 49 states and U.S. territories and QL5 IFSAR would be acquired for Alaska. [Alaska also has requirements for LiDAR data, but persistent cloud and fog conditions make it technically difficult and expensive to acquire LiDAR in Alaska, though some LiDAR has been acquired of small, priority areas within the state.]

Figure 1.2. Scenario 1, Uniform QL3 LiDAR nationwide except QL5 IFSAR for Alaska; 25-year acquisition period; lowest cost and lowest benefits scenario.

In Section 8 of this report, Table 8.2 accumulates the annual costs and benefits over the 25-year lifecycle of Scenario 1, including IT costs for data management and distribution; and Table 8.3 does the same for Scenario 1A. In comparing alternative datasets, Scenario 1 would result in the following annual costs and benefits from the LiDAR and IFSAR data, excluding IT costs for data management and dissemination.

Total Annual Data Costs: $32.7M/year	**Total Annual Data Benefits: $148.4M/year**
Data Benefit/Cost Ratio: 4.538	**Net Annual Data Benefits: $115.7M/year**

Scenario 1 Advantages

- Lowest annual and lifecycle costs of all scenarios.
- Upon completion, uniform QL3 LiDAR for 49 states and U.S. territories consistently produced to the current USGS *LiDAR Guidelines and Base Specifications*, v13.

Scenario 1 Disadvantages

- Poorest Quality Level and poorest update frequency of all scenarios.

- Fewest *mission-critical* requirements (12.6%) satisfied for Business Uses and Functional Activities.
- Lowest total and net benefits of all scenarios.
- Poorest Benefit/Cost Ratio of all scenarios.
- Nationwide coverage of enhanced elevation data is less likely, even with 25 years to complete coverage, because of the challenge of maintaining agreements and the likelihood that states and priority areas with available funding are likely to acquire data multiple times over a quarter century, while some areas will likely never be covered.

Alternative Scenario 1A, 15-year Acquisition Period

If Scenario 1 data were acquired using a 15-year acquisition period instead of 25-years, the following costs and benefits would apply for Scenario 1A:

Total Annual Data Costs: $54.5M/year	**Total Annual Data Benefits: $261.1M/year**
Data Benefit/Cost Ratio: 4.791	**Net Annual Data Benefits: $206.6M/year**

Scenario 1A Comparison with Scenario 1

Uniform QL3 LiDAR data would be available earlier (15 year cycle), satisfying more *mission-critical* requirements and yielding higher benefits. The annual costs for Scenario 1A ($54.5M /year) are higher than the annual costs for Scenario 1 ($32.7M/year), but the annual benefits for Scenario 1A ($261.1M /year) are also much higher than the annual benefits for Scenario 1 ($148.4M/year). The B/C Ratio changes from 4.538 for Scenario 1 to 4.791 for Scenario 1A.

Scenario 2 – Mixed QL1/2/3 LiDAR, 8-year Acquisition Period

As shown in Figure 1.3, under Scenario 2, QL2 LiDAR would be acquired for most of the 48 conterminous states with some QL1 LiDAR (burnt orange) and some QL3 LiDAR (yellow) cells and QL5 IFSAR for Alaska.

The data collected under Scenario 2 is optimized to provide the highest net benefit to the federal government, with no area receiving less than QL3 in the conterminous U.S. An update frequency of 8 years was chosen because the 6-10 year update frequency consistently provided the best Return on Investment.

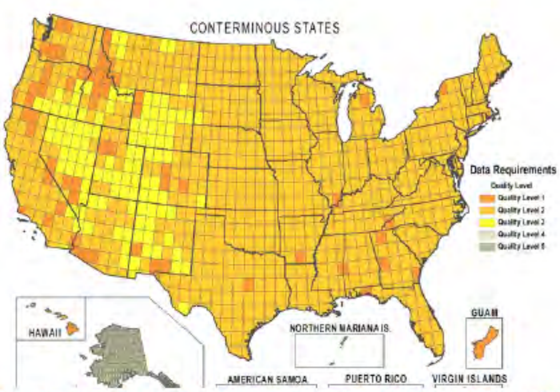


Figure 1.3. Scenario 2, mostly QL2 LiDAR nationwide with some QL1 and QL3 LiDAR; QL5 IFSAR for Alaska; 8-year acquisition period. This scenario has an optimal federal focus that benefits states and nongovernmental organizations also.

In Section 8 of this report, Table 8.4 accumulates the annual costs and benefits over the 8-year lifecycle of Scenario 2, including IT costs for data management and distribution, and Table 8.5 does the same for Scenario 2A. In comparing alternative datasets, Scenario 2 would result in the following annual costs and benefits from the LiDAR and IFSAR data, excluding IT costs for data management and dissemination:

Total Annual Data Costs: $134.6M/year	**Total Annual Data Benefits: $698.9M/year**
Data Benefit/Cost Ratio: 5.194	**Net Annual Data Benefits: $564.4M/year**

Scenario 2 Advantages

- Optimizes LiDAR Quality Levels to the variable needs of the federal government in different parts of the country. The data would also meet many state and nongovernmental Business Uses.
- Does not deliver data of higher accuracy and density than known to be needed by federal agencies.
- Complete nationwide coverage of mostly QL2 LiDAR in 8 years.
- While optimized to provide the highest federal B/C Ratio, Scenario 2 also provides the second highest lifecycle B/C Ratio (4.726) for all users combined.

Scenario 2 Disadvantages

- Nationwide coverage of LiDAR is non-uniform, with 70 QL1 LiDAR cells, 790 QL2 LiDAR cells, and 122 QL3 LiDAR cells. In Appendix F, Dewberry investigated several perceived anomalies pertaining to potential questions as to why some isolated cells justified QL1 LiDAR data compared with adjoining cells that justified QL2 or even QL3 LiDAR; the differences are usually subtle rather than clearly defined. Those looking at Figure 8.4 would inevitably wonder why only a single 1-degree cell of QL1 LiDAR per state is justified for TX, MI, AR, IL, NC, FL, NY and the MS/AL border; why only two QL1 LiDAR cells are justified for WY and UT, etc.
- The current USGS *LiDAR Guidelines and Base Specifications*, v13, are appropriate for QL3 LiDAR; v13 specifications would need to be modified slightly for the higher accuracy and higher density LiDAR for QL2 and QL1. Although the datasets would be compatible, with all three LiDAR Quality Levels included in Scenario 2, the LiDAR data would not be of uniform consistency.

Alternative Scenario 2A, 15-year Acquisition Period

If Scenario 2 data were instead acquired using a 15-year acquisition period instead of 8-years, the following costs and benefits would apply for Scenario 2A:

Total Annual Data Costs: $71.8M/year	**Total Annual Data Benefits: $353.2M/year**
Data Benefit/Cost Ratio: 4.919	**Net Annual Data Benefits: $281.4M/year**

Scenario 2A Comparison with Scenario 2

The annual costs for Scenario 2A ($71.8M/year) are nearly half the annual costs for Scenario 2 ($134.6M/year); however, the annual benefits from Scenario 2A ($353.2M/year) are also much lower than Scenario 2 ($698.9M/year). The B/C Ratio changes from 5.194 for Scenario 2 to 4.919 for Scenario 2A.

Scenario 3 – Uniform QL2 LiDAR, 8-year Acquisition Period

As shown in Figure 1.4, under Scenario 3, uniform QL2 LiDAR would be acquired nationwide except for QL5 IFSAR for Alaska. The acquisition period is 8 years.

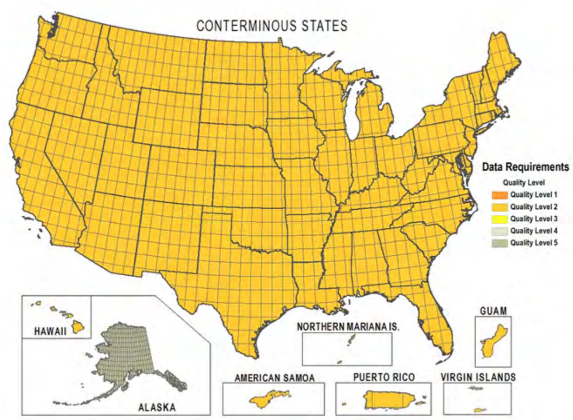


Figure 1.4. Scenario 3, Uniform QL2 LiDAR nationwide except QL5 IFSAR for Alaska; 8-year acquisition period; it focuses on maximizing net benefits for federal, state and nongovernmental Business Uses with uniform data and update cycles so that individual states are not differentiated; it also has high net benefits and a high B/C Ratio, nearly the same as Scenario 2.

Scenario 3 is a medium-cost alternative that would yield uniform QL2 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska; it offers high Net Benefits and a high Benefit/Cost Ratio.

In Section 8 of this report, Table 8.6 accumulates the annual costs and benefits over the 8-year lifecycle of Scenario 3, including IT costs for data management and distribution, and Table 8.7 does the same for Scenario 3A. In comparing alternative datasets, Scenario 3 would result in the following annual costs and benefits from the LiDAR and IFSAR data, excluding IT costs for data management and dissemination:

Total Annual Data Costs: $133.1M/year	**Total Annual Data Benefits: $689.9M/year**
Data Benefit/Cost Ratio: 5.184	**Net Annual Data Benefits: $556.8M/year**

Scenario 3 Advantages

- Uniform QL2 LiDAR for 49 states and U.S. territories consistently produced to the USGS *LiDAR Guidelines and Base Specifications*, upgraded from v.13 specifications to cover QL2 data.
- Continuous uniformity in data quality.
- High B/C Ratio (4.713), nearly equal to that of Scenario 2 (4.726).
- As in scenario 2, uniform LiDAR data for 49 states would facilitate the development of applications software for nearly every Business Use based on known accuracy and density parameters.

Scenario 3 Disadvantages

- Parts of the country (mountains and deserts) may be mapped to higher quality standards than clearly needed based on requirements.

Alternative Scenario 3A, 15-year Acquisition Period

If data were acquired using a 15-year acquisition period instead of 8-years, the following costs and benefits would apply for Scenario 3A:

Total Annual Data Costs: $71.0M/year	**Total Annual Data Benefits: $348.7M/year**
Data Benefit/Cost Ratio: 4.913	**Net Annual Data Benefits: $277.7M/year**

Scenario 3A Comparison with Scenario 3

The annual costs for Scenario 3A ($71.0M/year) are nearly half the annual costs for Scenario 3 ($133.1M/year); however, the annual benefits from Scenario 3A ($348.7M/year) are also much lower than Scenario 3 ($689.9M/year). The B/C Ratio changes from 5.184 for Scenario 3 to 4.913 for Scenario 3A.

Scenario 4 – Mixed QL1/2/3 LiDAR, 8-year Acquisition Period

As shown in Figure 1.5, under Scenario 4, QL2 LiDAR would be acquired for most of the 48 conterminous states with some QL1 LiDAR (burnt orange) for Hawaii, Oregon, Texas, Illinois, Guam and isolated QL1 cells elsewhere, four QL3 LiDAR cells (yellow), plus QL5 IFSAR for 21 cells plus Alaska (grey).

Scenario 4 is the alternative that is optimized to satisfy all federal/state/nongovernmental requirements and yields the highest combined net benefits and B/C Ratio. It is also the most expensive scenario.

Because dollar benefits were not provided by respondents for over half of the Functional Activities, the benefits are skewed towards those that did.

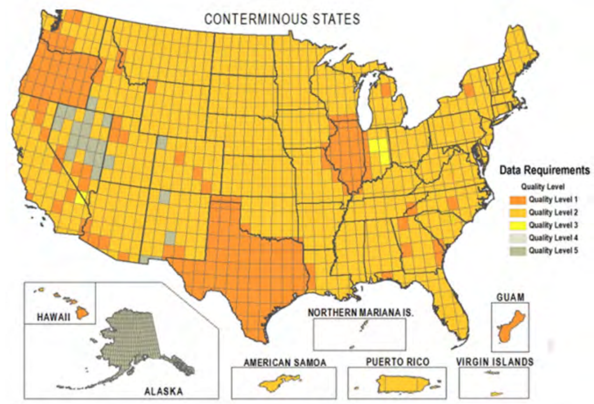


Figure 1.5. Scenario 4 Quality Levels, mostly QL2 LiDAR nationwide with larger QL1 areas; 8-year acquisition period. This scenario provides the highest net benefits for federal, state and nongovernmental users combined. Variations result from states that provided the highest dollar benefits for their specified Quality Levels.

In Section 8 of this report, Table 8.8 accumulates the annual costs and benefits over the 8-year lifecycle of Scenario 4, including IT costs for data management and distribution, and Table 8.9 does the same for Scenario 4A. In comparing alternative datasets, Scenario 4 would result in the following annual costs and benefits from the LiDAR and IFSAR data, excluding IT costs for data management and dissemination:

Total Annual Data Costs: $147.3M/year	**Total Annual Data Benefits: $780.3M/year**
Data Benefit/Cost Ratio: 5.297	**Net Annual Data Benefits: $633.0M/year**

Scenario 4 Advantages

- Provides the highest total benefits, highest net benefits, and highest B/C Ratio of any scenario.
- Highest *mission-critical* requirements (66.1%) satisfied for Business Uses and Functional Activities.
- Optimizes LiDAR Quality Levels to the variable needs of all partners in different parts of the country.

Scenario 4 Disadvantages

- Highest costs of any scenario.
- Provides four different Quality Levels, excluding Alaska, with some states clearly mapped to higher standards than others.

- Four states (HI, OR, TX, IL) would receive higher quality QL1 LiDAR data primarily because they estimated higher benefits of such data. This may be an artifact of the variability in state responses. If a national program was implemented using this scenario, respondents would be incentivized to provide or revise their estimated dollar benefits and the results could/would change as a result.
- Although fully compatible, the LiDAR data would be somewhat non-uniform since three Quality Levels would be produced.

Alternative Scenario 4A, 15-year Acquisition Period

If Scenario 4 were acquired using a 15-year acquisition period instead of 8-years, the following costs and benefits would apply for Scenario 4A:

Total Annual Data Costs: $78.6M/year	**Total Annual Data Benefits: $394.1M/year**
Data Benefit/Cost Ratio: 5.016	**Net Annual Data Benefits: $315.5M/year**

Scenario 4A Comparison with Scenario 4

The annual costs for Scenario 4A ($78/6M/year) are nearly half the annual costs for Scenario 4 ($147.3M/year); however, the annual benefits from Scenario 4A ($394.1M /year) are also much lower than Scenario 4 ($780.3M/year). The B/C Ratio changes from 5.297 for Scenario 4 to 5.016 for Scenario 4A.

Comparison of Implementation Scenarios

All prior discussion of costs, benefits and B/C ratios for the eight Scenarios pertained to data costs only, and did not include Dewberry's estimated costs for Information Technology (IT) infrastructure needed to injest, quality control, store, archive, process, and provide elevation data and derivative products to the public.

Table 1.9 compares the annual costs, benefits, net benefits, B/C Ratios, and percent of total possible benefits satisfied for these eight scenarios based on data costs plus IT infrastructure costs explained in detail in Appendix H. The table is sorted by scenario cost, from high to low. Scenario 4 provides the highest annual net benefits nationwide and satisfies the highest percentage (66.1%) of *mission-critical* needs for enhanced elevation data; however, it is also the most expensive and appears to favor Guam, Hawaii, Oregon, Texas and Illinois for QL1 LiDAR data because those states estimated much higher benefits of QL1 LiDAR than did the other states (Guam's benefits accrued from Defense Department needs).

Scenarios 1, 2 and 3 provide nationwide implementation scenarios that appear more balanced. Scenario 1 will take 25 years, satisfies the lowest percentage (12.6%) of the *mission-critical* requirements for enhanced elevation data, and probably would not result in nationwide coverage at the end of 25 years. Scenarios 2 and 3 both have nearly the same costs and benefits, both are priced in the mid-range, and result in B/C Ratios of over 4.7:1 and satisfy approximately 59% of the *mission-critical* requirements based on reduced value-multipliers when receiving less than the Quality Levels and update frequencies specified for each Functional Activity.

Table 1.9. Lifecycle Benefit Cost Analysis Comparisons for Elevation Data + IT Costs Combined

All Scenarios include QL5 IFSAR for Alaska	Average Annual Costs	Average Annual Benefits	Average Annual Net Benefits	B/C Ratio	Total Possible Benefits Satisfied
Scenario 4, QL1/2/3/5 data, 8 years, focus on highest combined net benefits for all users	$160.6M	$780.2M	$619.7M	4.858	66.1%
Scenario 2, QL1/2/3 LiDAR, 8 years, focus on federal requirements with highest B/C Ratio	$147.9M	$698.9M	$551.0M	4.726	59.2%
Scenario 3, Uniform QL2 LiDAR, 8 years, focus on nationally uniform data with highest B/C Ratio	$146.4M	$689.9M	$543.5M	4.713	58.5%
Scenario 4A, QL1/2/3/5 data but 15-year update	$85.7M	$394.1M	$308.4M	4.600	33.4%
Scenario 2A, QL1/2/3 LiDAR but 15-year update	$78.9M	$353.2M	$274.3M	4.478	29.9%
Scenario 3A, Uniform QL2 LiDAR but 15-year update	$78.1M	$348.7M	$270.6M	4.471	29.5%
Scenario 1A, Uniform QL3 LiDAR but 15-year update	$58.5M	$261.1M	$202.6M	4.461	22.1%
Scenario 1, Uniform QL3 LiDAR, 25-years, focus on lowest costs	$35.1M	$148.4M	$115.7M	4.226	12.6%

Technology Opportunities and Risks

In Appendix G, Dewberry evaluated the risks and opportunities to a nationwide elevation program from a variety of technology factors, including: (1) future changes to airborne topographic and bathymetric LiDAR and IFSAR technologies; (2) future changes to enabling technologies, including inertial measurement units, airborne GPS, and Continuously Operating Reference Stations (CORS); (3) future changes to the geoid model and vertical datum resulting from the National Geodetic Survey (NGS) Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project; (4) assessment of the capacity of commercial LiDAR vendors to collect and process data for scenarios with shorter data collection cycles in a timely and cost-effective manner; (5) the continued evolution of LiDAR standards and guidelines and QA/QC procedures; (6) the evolution of “cloud computing” and uncertainties in the ability and/or intent of emerging geospatial websites; and (7) potential risks from uncertainties impacting a nationwide elevation program.

Dewberry concluded that none of these change and risk factors should delay implementation of a nationwide program based primarily on LiDAR for most of the U.S., and based primarily on IFSAR for most of Alaska.

Summary of Findings and Conclusions

1. Although there are approximately a half million online data downloads annually from the National Elevation Dataset (NED), the differences between "what users get" from the NED and "what users need" are summarized in Table 1.10 (further explained in Section 3 of this report).

Table 1.10. Issues with the National Elevation Dataset (NED)

What users have	What users need
Currently, approximately 28.4% of the lower 49 states and D.C. has LiDAR data, and approximately 15.2% of Alaska has IFSAR data; nationwide, enhanced elevation datasets are growing at a slow annual rate and some states might never be mapped	Total U.S. coverage with enhanced elevation data.
Most DEMs in the NED were produced from old quad maps accurate to 5-10 feet at the 90% confidence level	Most Business Uses require DEMs accurate to 6-12 inches at the 90% confidence level
Most DEMs in the NED have 1/3-arc-second (10-meter) post spacing	Require high-resolution DEMs nationwide with 1/27-arc-second (1-meter) post spacing
Most DEMs in the NED were produced from quad maps 30-50 years old	Require current DEMs nationwide with update frequencies no greater than 10 years.
Hydro-flattened DEMs in the NED where bridges and culverts impede the flow of water in hydrologic models	Require both hydro-flattened and hydro-enforced DEMs where bridges/culverts are "cut" so DEMs model the actual flow of water
All DEMs in the NED are gridded Digital Terrain Models (DTMs) of the bare-earth terrain	Require both gridded DTMs and Digital Surface Models (DSMs) of tree tops, roof tops, towers, etc.
No contours or hillshades are provided	Both contours and hillshades are required
From USGS' Elevation Derivatives for National Applications (EDNA) program, some slope and aspect data are available from low resolution DEMs (30-meter post spacing)	Require nationwide slope and aspect data from higher resolution DEMs (3-meter or 1-meter post spacing)
LiDAR point cloud data are partially provided by USGS and other agencies	Require reliable comprehensive access to LiDAR point cloud data that supports diverse applications analysis of above ground features including vegetation structure
Poor metadata where currency, accuracy and data production methods are often unknown	Require good metadata where currency, accuracy and data production methods are well documented
Inadequate data discovery mechanisms to know what data are available nationwide and plans for future acquisitions and partnerships.	Require improved data discovery mechanisms to support increased partnering among federal, state and local agencies.
Elevation data acquired by state and local governments are often nonstandard and cannot be entered in the NED; some datasets are proprietary and not in the NED.	Require common Guidelines and Specifications so that data acquired by diverse federal, state and local governments is more consistent, and is more useful for updating the NED.

2. A total of 27 predefined Business Uses (Table 1.1) were established for the NEEA. Federal, state and nongovernmental Points of Contact (POCs) validated 458 Functional Activities with geographic area requirements for enhanced elevation data with one of five Quality Levels (Table 1.2) and one of five update frequencies: (1) annual, (2) 2-3 years, (3) 4-5 years, (4) 6-10 years, and (5) >10 years. Although they indicated that enhanced elevation data were *mission-critical* with major time/cost benefits and/or major customer service benefits, organizations were unable to estimate dollar benefits for slightly over half of all Functional Activities. This caused Dewberry to also consider "most-requested" Quality Levels and update frequencies, in addition

to dollar benefits, were used in developing some of the scenarios in the Benefit Cost Analyses. To give some weight to all requirements, with or without estimated dollar benefits, Dewberry determined the most-requested Quality Levels and update frequencies for each 1-degree cell and considered these requirements in development of alternative program implementation scenarios for which Benefit Cost Analyses were performed

3. As tabulated in Table 1.3, the conservatively-estimated benefits are $1.180 billion/year if all Quality Levels and update frequency requirements are satisfied; and the potential benefits are over ten times higher, i.e., $12.981 billion/year. However, for all potential scenarios, actual benefits would be lower than these numbers whenever actual Quality Levels and update frequencies are poorer than the Quality Levels and update frequencies required for each Functional Activity. This is the reason why none of the eight implementation scenarios in Table 1.9 satisfies 100 percent of the *mission-critical* requirements.

4. As also shown in Table 1.3, the highest conservatively-estimated benefits for Business Uses, as used in all Benefit Cost Analyses for the NEEA are: (1) Flood Risk Management ($295M/year); (2) Infrastructure and Construction Management ($206M/year); (3) Natural Resources Conservation ($159M/year); (4) Precision Agriculture ($122M/year); and (5) Water Supply and Quality ($85M/year), followed by (6) Wildfire Management ($76M/year).

5. Much higher potential benefits for Business Uses could be realized in the following areas: (1) BU#18 Land Navigation and Safety ($7B/year); (2) BU#8 Precision Agriculture ($2B/year); and (3) BU#9 Geologic Resource Assessment and Hazard Mitigation ($1B/year). This shift does not signal that the benefits to Flood Risk Management are declining; instead it shows that Flood Risk Management is a relatively mature Business Use for LiDAR whereas the benefits of LiDAR will emerge for Land Navigation and Safety, Precision Agriculture, and Geologic Resource Assessment and Hazard Mitigation and other Business Uses as LiDAR data become available nationwide and as other technologies emerge. The primary evidence for this trend comes from the following Business Uses documented in Appendices B and D:

    a. For BU#18, Land Navigation and Safety, TomTom, the world's leading provider of in-car location and navigation products and services, validated expectations that most leading car and truck manufacturers, starting in 2014, will introduce new automatic transmission control technology, based on 3-D road geometry from airborne LiDAR, to achieve improved fuel efficiency between 4 and 14 percent. Using even a 1 percent improvement, the savings amount to $6 billion per year. In its November, 2010 report (FHWA-HRT-10-073) entitled: *Roadway Geometry and Inventory Trade Study for IntelliDrive℠ Applications*, the Federal Highway Administration (FHWA) documented the results of a trade study on roadway geometry and inventory data. The study objective was to identify and evaluate existing and emerging technical solutions for providing and updating 3-D roadway geometry and other roadway inventory information likely to be needed for IntelliDrive℠ applications. The report is useful to federal, state and local government agencies, research organizations, and private sector firms that will research, develop and deploy IntelliDrive℠ techniques. The report documents the use of

IFSAR and mobile LiDAR for centerlines, curves and grades. It also validated TomTom's assurance that this emerging technology will be deployed nationwide in a few years.

b. For BU#8, Agriculture and Precision Farming, the J.R. Simplot Company, a leading provider of LiDAR-based precision agriculture services, and Ellingson Drainage, a leading provider of agricultural drainage solutions based on LiDAR, both expect that LiDAR data will significantly improve farm yield, reduce farm runoff, and help solve drainage issues for small, medium and large farms, with benefits of several billion dollars annually, when LiDAR data become available for agricultural lands nationwide and equipment manufacturers make this new technology routinely available to farmers.

c. For BU#9, Geologic Resource Assessment and Hazard Mitigation, federal and state geologists are adamant that high quality LiDAR will enable them to identify geologic faults and either prevent or modify the construction of key infrastructure and sensitive facilities in the vicinity of such faults, saving lives and potentially billions of dollars annually in costs avoided. Geologists from the Nuclear Regulatory Commission (NRC) in its Functional Activity entitled "Nuclear Power Plant Site Natural Phenomena Hazard Assessment and Risk Mitigation," and geologists from the National Science Foundation (NSF) in its Functional Activity entitled "EarthScope Initiative," support this conclusion. The BU#9-related Functional Activities from USGS, NRC and NSF can be reviewed in detail in Appendix B.

6. For each of the 458 Functional Activities, Dewberry conservatively-estimated the total benefits for 25 options, including all combinations of five Quality Levels and five update frequencies. These benefits from potentially hundreds of overlapping Functional Activities in the master geodatabase were then aggregated by 1-degree cell (1-degree latitude by 1-degree longitude) to determine the Quality Level and update frequency for each cell that provided the highest net benefits (total benefits minus total data costs for each cell).
7. Table 1.4 shows how data costs were estimated for enhanced elevation data at different Quality Levels, based on the efficient data acquisition in large, rectangular 1-degree cells rather than small, irregularly shaped areas that are typically acquired at higher costs. Table 1.5 shows how dollar benefits are reduced in Dewberry's Benefit/Cost model for each Functional Activity if the required Quality Level and update frequency is poorer than required.
8. Table 1.6 shows the synergistic results of a national program where combined costs and benefits are more favorable when compared with federal, state and/or nongovernmental sectors justifying their own elevation data acquisition programs independently
9. Table 1.7 evaluates and compares 25 options (five update frequencies for five Quality Levels) for collecting uniform data at a uniform update frequency for the 48 conterminous states.
10. Table 1.8 and Figure 1.1 show the current status of the status quo which is widely considered to be limiting because of a slow acquisition rate for enhanced elevation data (2-3% per year). Even after 35 years, portions of the country would remain unmapped whereas other areas would be remapped multiple times. Although every dollar spent on LiDAR yields between $4 and $5 in

benefits, about 90 percent of the maximum possible benefits remain unrealized because *mission-critical* business needs are not being met.

11. Figure 1.2 shows the uniform QL3 LiDAR (plus QL5 IFSAR for Alaska) acquired over a 25-year acquisition period for Scenario 1. This scenario could be either partly centralized or fully centralized. This is the lowest-cost scenario, and it also provides the lowest benefits and satisfies the lowest percentage of *mission-critical* requirements for enhanced elevation data. About 12.6 percent of the maximum possible benefits are realized, and about 87.4 percent of those benefits remain unrealized because *mission-critical* business needs are not being met.
12. Figure 1.3 shows variable elevation data Quality Levels acquired over an 8-year acquisition period for Scenario 2. This medium-cost scenario would best be managed as partly centralized because of partner involvement in different Quality Levels. Except for QL5 IFSAR for Alaska, Scenario 2 uses QL3 LiDAR as the baseline for all states and U.S. territories nationwide -- then upgrades individual 1-degree cells to QL2 or QL1 depending on federal government requirements and benefits only, based on either the highest net benefits or the most-requested Quality Levels. This scenario has a high B/C Ratio (4.726). About 59.2 percent of the maximum possible benefits are realized from *mission-critical* business needs being met, and about 40.8 percent of those benefits remain unrealized.
13. Figure 1.4 shows the uniform QL2 LiDAR (plus QL5 IFSAR for Alaska) acquired over an 8-year acquisition period for Scenario 3. This medium-cost scenario could be either partly centralized or fully centralized. Because costs and benefits are so similar to Scenario 2, about 58.5 percent of the maximum possible benefits are realized from *mission-critical* business needs being met, and about 41.5 percent of those benefits remain unrealized.
14. Figure 1.5 shows variable elevation data Quality Levels acquired over an 8-year acquisition period for Scenario 4. This scenario would best be treated as partly centralized because of needed partner involvement in different Quality Levels. Scenario 4 specifies four different Quality Levels in the 48 conterminous states plus QL5 IFSAR for Alaska but this could change as states adjust their estimated benefits. This highest-cost scenario also yields the highest benefits of any scenario and the highest B/C Ratio (4.858). About 66.1 percent of the maximum possible benefits are realized from *mission-critical* business needs being met, and about 33.9 percent of those benefits remain unrealized. This scenario favors the four states that estimated higher benefits from statewide QL1 LiDAR data.
15. Both Scenarios 2 and 3 are improvements to Scenario 1 which only satisfies 12.6 percent of *mission-critical* requirements. With lifecycle Benefit/Cost Ratios of 4.726 for Scenario 2 and 4.713 for Scenario 3, the costs and benefits for Scenario 2 and 3 are nearly identical, although there is a difference in the Quality Levels to be acquired for 192 1-degree cells.
16. All four primary scenarios yield high lifecycle Benefit/Cost Ratios between 4.226:1 and 4.858:1 using only the conservatively-estimated benefits in all Benefit Cost Analyses. If the potential benefits had instead been used in the Benefit Cost Analyses, the B/C Ratios would be approximately 10 times higher.
17. Regardless of implementation scenario chosen, the Quality Level and age of the current inventory of enhanced elevation data may be a factor in sequencing new data collection independent of the implementation scenario chosen.

18. The Government and its partners will decide what LiDAR point cloud data, gridded DTMs and DSMs, and various elevation derivative products will be served to the public and how such data will be served to the public. They will also decide what guidelines and specifications and QA/QC procedures will be used for standard elevation products and derivatives.
19. A centralized Information Technology (IT) infrastructure is needed to support the management and dissemination of enhanced elevation data. This infrastructure will ensure that data are managed according to standardized practices and that the public has a single access point to the data.
20. The average annual lifecycle costs for hardware, software, and IT support staff will range from an estimated low of $2.5M/year for Scenario 1 (25-year scenario) to a high of $13.25M/year for Scenarios 2, 3 and 4 (8-year scenarios), depending on the specific program requirements for the infrastructure.
21. Although it will not satisfy the Quality Level requirements for the vast majority of Functional Activities, NEXTMap® USA QL5 IFSAR datasets from Intermap Technologies, Inc. are available for licensing in 49 states (all except Alaska) in the form of DTMs, DSMs and ortho-rectified radar imagery (ORI). Existing NEXTMap® USA data, currently 2 to 6 years old, could be placed in the public domain at a relatively low cost (<$16/mi^2), subject to negotiation. NEXTMap® USA data are not available for Alaska.
22. Regardless of which Scenario is selected, uncertain future funding is a primary challenge to any nationwide implementation scenario for enhanced elevation data acquisition, lifecycle management and maintenance.
23. Private companies are or may be developing commercial elevation datasets derived from high resolution imagery and/or other technologies that may be relevant for consideration in future program implementations. Some of these commercial products may include Digital Surface Models and Digital Terrain Models at various levels of relative and absolute accuracy and may be licensed and not available for public distribution. During the NEEA study, 50.6 percent of questionnaire respondents indicated that their Business Use requirements would not be satisfied if they were not allowed to redistribute the data. As specific products are introduced in the marketplace, analysis will be needed to determine to what extent a data offering and any restrictions can meet known needs, how restrictions would effect mission accomplishment, and how well a given solution fits into an overall national program.

2. Introduction

LiDAR, an acronym for Light Detection And Ranging, has emerged as an essential remote sensing technology needed to support high-value applications that rely on elevation data, to include flood risk management, water supply and quality, infrastructure and construction management, natural resources conservation, geologic resource assessment and hazard mitigation, and dozens of other applications called Business Uses in this report. In addition to traditional photogrammetry, LiDAR is one of two other primary technologies used in the United States to support mapping of elevation and other Earth surface characteristics such as built features and vegetation structure. Interferometric Synthetic Aperture Radar (IFSAR), while lower in accuracy, has the advantage of being able to penetrate cloud cover and a lower initial data acquisition cost. LiDAR produces elevation data of higher elevation accuracy and is better at penetrating dense vegetation for mapping of the bare-earth terrain.

Federal agencies including the U.S. Geological Survey (USGS), Natural Resources Conservation Service (NRCS), National Oceanic and Atmospheric Administration (NOAA), Federal Emergency Management Agency (FEMA), National Geospatial-Intelligence Agency (NGA), and the U.S. Army Corps of Engineers (USACE) are making significant investments in LiDAR data collection programs to support key missions. In addition, several states have either completed statewide projects or are actively planning LiDAR programs. Elevation data collection projects are usually coordinated with multiple funding organizations. Projects are limited to the geographic areas where funding and common requirements coincide, and data consistency often varies from project to project. These limitations compromise any analysis over large geographic areas or any place an operational need crosses project boundaries.

About 75 percent of the National Elevation Dataset (NED) source data is more than 30 years old and is not sufficiently accurate to meet user requirements for most applications. Since 2003, the USGS has been incorporating high-resolution elevation data derived from LiDAR into the NED. At typical annual funding levels for federal and state governments, it could take 35 years to acquire LiDAR coverage for the 48 conterminous states, and even then some areas would remain unmapped whereas other areas would be remapped several times over.

As LiDAR technology has gained widespread acceptance, discussions within the LiDAR user community have turned toward improved coordination and planning programs of national scope. The National Enhanced Elevation Assessment (NEEA) study was undertaken to identify more efficient and robust approaches for meeting priority national elevation requirements. This assessment was sponsored by member agencies of the National Digital Elevation Program (NDEP), including the USGS, NGA, NRCS, FEMA, and NOAA.

2.1 Assessment Goals

This NEEA was undertaken to more fully understand federal, state, local, tribal and other national business requirements, benefits and costs associated with various program implementation scenarios. The scenarios provide planning options for a potential national program optimized to balance cost and benefits in meeting priority federal, state, local and other national information needs. This assessment also addresses fundamental questions prior to detailed program planning, such as: Is it more cost effective for the government to manage elevation activities within the context of a national program?

Are there additional national or agency benefits derived from such a strategy? What does the optimized program look like?

This assessment includes public and private input from federal and state governments and nongovernmental organizations to consolidate requirements and benefits for determination of optimal solutions to satisfy a broad range of national needs. This assessment helps discover economies of scale, potential multiple data uses, and universal business requirements that can be met through a more comprehensive national strategy for improving elevation data in the United States and its territories, including coastlines.

2.2 Project Scope

This assessment was conducted under USGS' Geospatial Products and Services Contract 2 (GPSC2) with Dewberry, headquartered in Fairfax, Virginia. Under a GPSC2 task order, USGS tasked Dewberry to conduct a study to develop and refine requirements and to identify implementation alternatives and associated benefits and costs for a National Enhanced Elevation Data Program that meets federal, state and other national Business Uses and needs. The study's findings are expected to establish a baseline understanding of national Business Uses for, and the associated benefits from, enhanced national elevation data. The report findings would help improve the responsiveness of USGS and partner agency programs, and inform the design of an enhanced future program that balances requirements, benefits and costs at a national scale.

The first task was to comprehensively document and validate federal, state, local, and tribal government and nongovernmental (not-for-profit and private business) needs for enhanced elevation data. These needs, as well as cost and benefit information, have been documented for each participating organization. A three-step process included: 1) an online questionnaire 2) follow-on workshops and interviews with key managers to complete and consolidate responses, and 3) validation of this information for participating organizations. This information is provided for federal, state, local, tribal and nongovernmental organizations in Appendices B, C and D.

Follow-on tasks included:

- Analyses of Business Use and benefits information to develop proposed standardized national dataset options that will address key Business Uses.
- Evaluation of emerging technology trends and technical limitations to provide a high-level technical approach and costs for implementing a national program over a 4-7 year timeframe; identify where radar may be an alternative to LiDAR; and identify current bathymetric LiDAR technologies.
- Assessment of the feasibility, cost, and performance of data infrastructure alternatives for services such as ingesting and managing a range of minimally processed LiDAR data from federal and state agencies, generating customized derivative products, and delivering high volumes of data.

- Evaluation and comparison of alternative program scenarios based on their expected ability to produce the optimized dataset options in terms of costs, risks, operational efficiency and other feasibility issues.

2.3 Project Approach

User requirements for topographic data were defined at five potential data Quality Levels (QLs) based on candidate technologies including topographic LiDAR, photogrammetry, and airborne IFSAR. Requirements for near-shore bathymetric LiDAR data were also defined. On-line questionnaires (see Appendix J) were answered by hundreds of federal and state/local elevation data users. Questionnaires were designed to determine expected benefits to be realized from enhanced elevation data for existing Business Uses and to identify new benefits to be realized from new Business Uses enabled by enhanced elevation data. Organizations summarized this requirements and expected benefits information into an aggregate total of 458 Functional Activities within 27 pre-defined Business Uses. Functional Activities simply refer to applications for enhanced elevation data as named and described by the participating organizations. Each Functional Activity was linked with one of the Business Use categories. Results were aggregated by Business Use and organization. Respondents also provided the applicable geographic area for each Functional Activity.

Extensive interviews were conducted with key managers and elevation data users from federal agencies/programs, as well as managers of state/local and nongovernmental organizations to: (1) validate and aggregate agency requirements at the different Quality Levels; (2) determine how often elevation datasets need to be updated; (3) identify the core missions of the participating organizations, and (4) evaluate tangible and intangible benefits of enhanced elevation data.

Working closely with USGS, Dewberry performed five major tasks in accordance with Section C, Statement of Work for Task Order No: G10PD01691 under USGS Contract No. G10PC00013. The five major tasks include:

1. Documenting Business Uses and inventorying existing and planned elevation data collection
2. Aggregating and analyzing the Business Use and elevation data to define candidate enhanced elevation datasets and products that meet a majority of business needs
3. Assessing emerging data collection technologies and related issues
4. Developing enterprise information technology (IT) infrastructure alternatives, and
5. Developing program implementation scenarios that address technical, risk, and cost-benefit considerations.

2.4 Report Overview

Section 3 of this report provides a review of related relevant reports from the Congressional Research Service (CRS) and the National Research Council (NRC); explanations of The National Map; the National Elevation Dataset (NED); the Center for LiDAR Information, Coordination and Knowledge (CLICK); the Elevation Derivatives for National Applications (EDNA) Web site; the National Digital Elevation Program (NDEP), ; the Ramona GIS Inventory site; the OpenTopography Portal; the NOAA Digital Coast; and issues with the status quo, defined largely by the latest NED Release Notes at Appendix A.

Section 4 of this report explains the methodology for information gathering, to include: (1) the Project Management Plan; (2) the questionnaire process; (3) the interview/workshop process; (4) the validation process; (5) the geodatabase process; and (6) and the USGS inventory of existing elevation datasets in the public domain. Appendix B includes the validated Appendices from 34 federal government agencies with 104 Functional Activities having mission-critical requirements for enhanced elevation data. Appendix C includes the validated Appendices from 50 states and two U.S. territories with 329 Functional Activities; plus 57 counties, 17 cities and towns, and 11 tribes and 22 regional governments with a combined total of 144 Functional Activities with mission-critical requirements for enhanced elevation data. Appendix D includes validated Appendices from 13 nongovernmental organizations, including one not-for-profit and 12 private businesses with *mission-critical* requirements for enhanced elevation data. If a Functional Activity contained multiple data Quality Level requirements, each Quality Level was counted and analyzed as a separate Functional Activity.

Section 5 of this report explains the methodology for data aggregation and analysis, to include the analysis of Business Use requirements and benefits documented in Appendix E; elevation data cost estimates and Benefit Cost Analyses (BCA) documented in Appendix F; and the BCA results.

Section 6 of this report evaluates emerging data collection technologies, including topographic and bathymetric LiDAR and IFSAR, as well as technical issues that could affect our ability to satisfy Business Uses, costs of implementing a national program, and developments that might affect the timing and duration of such a program. Section 6 summarizes the major conclusions from Appendix G, Technology Trends and Risk Considerations.

Section 7 of this report evaluates information technology (IT) infrastructure alternatives. Section 7 summarizes the major conclusions from Appendix H, Information Technology Infrastructure.

Section 8 of this report evaluates eight Nationwide Program Implementation Scenarios to address key questions asked of this study: 1) Is it more cost effective for the government to manage these activities within the context of a national program? 2) Are there additional national or agency benefits derived from such a strategy? 3) What does the optimized program look like? While Dewberry was tasked to present the major advantages and disadvantages as factually as possible for each implementation scenario, it remains a government responsibility to determine the best course of action for a potential National Enhanced Elevation Program.

3. Background

This section provides a review of related relevant reports from the Congressional Research Service (CRS) and the National Research Council (NRC); explanations of The National Map; the National Elevation Dataset (NED); the Center for LiDAR Information, Coordination and Knowledge (CLICK); the Elevation Derivatives for National Applications (EDNA) Web site; the National Digital Elevation Program (NDEP); the Ramona GIS Inventory site; the OpenTopography Portal; and the NOAA Digital Coast.

3.1 Relevant Reports

A literature search identified three published reports directly relevant to the National Enhanced Elevation Assessment.

Congressional Research Service (CRS) Report

On January 23, 2010, the Congressional Research Service (CRS) published a report entitled: *Geospatial Information and Geographic Information Systems (GIS): Current Issues and Future Challenges*. See Figure 3.1. The Summary page of this CRS report states the following:

> "Congress has recognized the challenge of coordinating and sharing geospatial data from the local, county, and state level to the national level, and vice versa. The cost of geospatial information to the federal government has also been an ongoing concern. As much as 80% to 90% of government information has a geospatial component, according to different sources. The federal government's role has changed from being a primary provider of authoritative geospatial information to coordinating and managing geospatial data and facilitating partnerships."

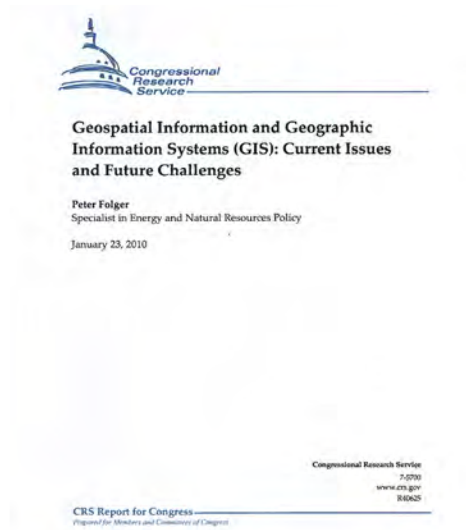


Figure 3.1. Cover of the CRS report that uses FEMA's need for accurate digital elevation data as an example of issues and challenges for The National Map.

This CRS report references a 2009 National Research Council (NRC) report, summarized below, that recommends that FEMA should increase its collaboration with federal, state and local government agencies to acquire high-resolution and accurate elevation data across the nation.

This CRS report summarized issues with organization and management, data sharing, and coordination: "Producing floodplain maps, conducting the Census, planning ecosystem restoration, and assessing vulnerability and responding to natural hazards such as hurricanes and earthquakes are examples of how federal agencies use GIS and geospatial information to meet national needs. The amount of government information that has a geospatial component – such as address or other reference to a physical location – is as much as 80 percent, according to the Department of Interior. According to one report, geospatial-related industries generate at least $30 billion annually, and the U.S. Bureau of Labor cites statistics that suggest the geospatial sector has been growing by about 35 percent per year, with the commercial side growing at 100 percent per year."

Elevation Data for Floodplain Mapping

A 2007 NRC report, relevant to the NEEA, was entitled: *Elevation Data for Floodplain Mapping* (Figure 3.2). The report's major conclusions and recommendations are paraphrased as follows:

- Existing elevation data are inadequate to support FEMA's needs.
- Nationwide LiDAR data are required with 2-foot contour accuracy in most terrain and 1-foot contour accuracy in very flat coastal or inland floodplains.
- Nationwide LiDAR has applications well beyond FEMA's Map Modernization program.
- As part of a national program, federal, state, and local mapping partners should have the option to request data that exceed minimum specifications if they pay the additional cost of data collection and processing necessary to achieve higher accuracies.
- The nationwide LiDAR data should be disseminated to the public as part of an updated National Elevation Dataset (NED).
- The NED should contain the original LiDAR mass points and edited bare-earth surface as well as any breaklines required to define essential linear features.
- Hydrologically corrected DEMs, stream networks, shorelines and other secondary elevation products should be provided.
- Standards and interchange formats should be developed for LiDAR data collection and processing as well as secondary (derivative) elevation products.

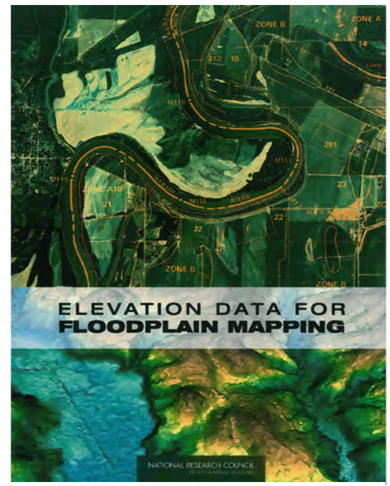


Figure 3.2. Cover of the 2007 NRC report that recommends nationwide LiDAR as part of the updated NED.

Mapping the Zone: Improving Flood Map Accuracy

Because of concerns about inaccurate Flood Insurance Rate Maps (FIRMs), a 2009 NRC report, relevant to the NEEA, was entitled: *Mapping the Zone: Improving Flood Map Accuracy (*Figure 3.3). The report's major Findings and Recommendation are quoted below:

- "Topographic data are the most important factor in determining water surface elevations, base flood elevation, and the extent of flooding and, thus, the accuracy of flood maps in riverine areas.
- "FEMA's transition to digital flood mapping during the Map Modernization Program creates opportunities for significant improvements in the communication of flood hazards and flood risks through maps and web-based products.
- "FEMA should increase collaboration with federal (e.g., USGS, NOAA, U.S. Army Corps of Engineers), state, and local government agencies to acquire high-resolution, high-accuracy topographic and bathymetric data throughout the nation."

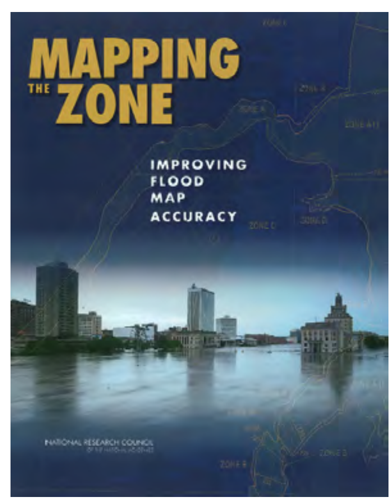


Figure 3.3 Cover of the 2009 NRC report that identified accurate elevation data as the most important factor in mapping & communicating flood risk.

Although the benefits of improved accuracy are difficult to quantify, an entire chapter in this NRC report was devoted to the benefits and costs of accurate flood mapping, as summarized in Table 3.1 extracted from this NRC report.

Table 3.1. Benefits and Costs of Improved Flood Map Accuracy

Category	Impact	Benefits	Costs
Land use: floodplain regulations	Reduced loss of life	• Able to target higher-risk areas • Able to identify evacuation needs	
	Reduced loss of property	• Able to target higher-risk areas • Lower-risk areas less restricted • Building restrictions match risk • Less time and money spent on contesting maps • Eventual payback on freeboard costs • Wise floodplain investment, including infrastructure	• Increased construction costs • Loss of land to development • Need to update regulations and inform the public of changes
	Reduced loss of business	• Fewer business interruptions • Fewer public service interruptions	• Increased construction costs
	Preservation of natural functions of floodplains	• Natural storm water management • Improved water quality • Increased ecological diversity	• Loss of land to development
Insurance	Rates	• Structures insured at appropriate levels • More consistent insurance ratings through better information about risk	• Rates may increase for some
	Coverage	• More insurance purchased because of improved understanding of risk	
	Property values	• Lower (or no) devaluations because of better information on risk • Change in practices that have led to devaluations	
Emergency services	Resource deployment	• More efficient allocation in planning and response	

3.2 The National Map

The National Map is a collaborative effort of the United States Geological Survey (USGS) and other federal, state, and local agencies to improve and deliver topographic information for the United States. The purpose of the effort is to provide "…a seamless, continuously maintained set of public domain geographic base information that will serve as a foundation for integrating, sharing, and using other data easily and consistently."

The National Map is part of the USGS National Geospatial Program. The geographic information available includes orthoimagery (aerial photographs), elevation, geographic names, hydrography, boundaries, transportation, structures and land cover. *The National Map* is accessible via the Web, as products and services, and as downloadable data. Its uses range from recreation to scientific analysis to emergency response.

The National Map is a significant contribution to the National Spatial Data Infrastructure (NSDI) and currently is being transformed to better serve the geospatial community by providing high quality, integrated geospatial data and improved products and services including new generation digital topographic maps. In addition, The National Map is foundational to implementation of the U.S. Department of the Interior (DOI) Geospatial Modernization Blueprint. The National Map is the official replacement for the USGS topographic map program. The National Elevation Dataset (NED) is the elevation layer of *The National Map*.

3.3 National Elevation Dataset (NED)

The National Elevation Dataset (NED) is the primary elevation data product of the USGS. The NED is a seamless dataset with the best available raster elevation data of the conterminous United States, Alaska, Hawaii, and territorial islands. The NED is updated on a nominal two month cycle to integrate newly available, improved elevation source data. All NED data are public domain. The NED is derived from diverse source data that are processed by USGS to a common coordinate system and unit of vertical measure. NED data are distributed in geographic coordinates in units of decimal degrees, and in conformance with the North American Datum of 1983 (NAD 83). All elevation values are in meters and, over the conterminous United States, are referenced to the North American Vertical Datum of 1988 (NAVD 88). The vertical reference will vary in other areas. As shown at Figure 3.4, NED data are available nationally (except for Alaska) at resolutions of 1-arc-second (about 30 meters) and 1/3-arc-second (about 10 meters), and in limited areas at 1/9-arc-second (about 3 meters). In most of Alaska, only lower resolution source data are available. As a result, most NED data for Alaska are at 2-arc-second (about 60 meters) grid spacing, Part of Alaska is available at the 1- and 1/3-arc-second resolution, and plans are in development for a significant improvement in elevation data coverage of the state. See ned.usgs.gov.

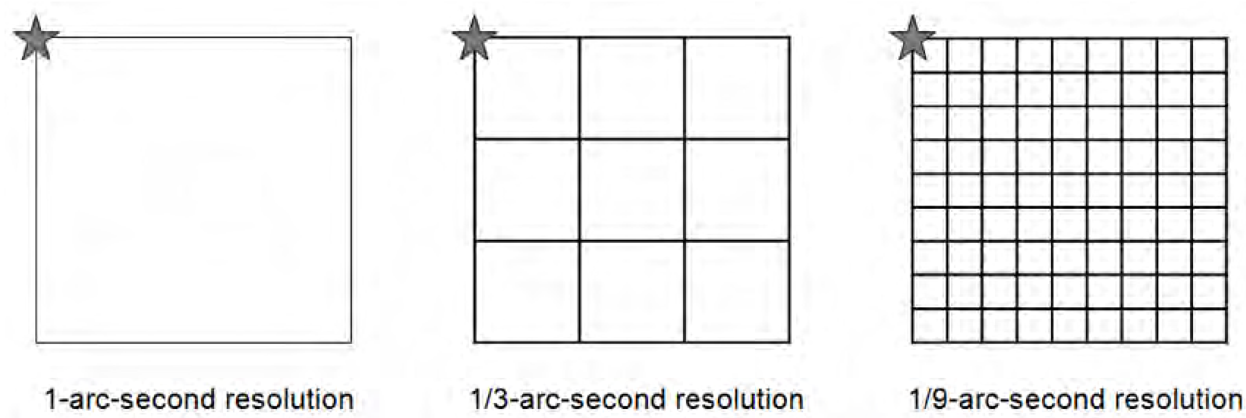


Figure 3.4. NED nested multi-resolution raster elevation layers. The area represented by one elevation post (or cell) in the 1-arc-second layer is represented by nine elevation posts in the 1/3-arc-second layer and by eighty-one elevation posts in the 1/9-arc-second layer.

As the elevation layer of *The National Map*, the NED provides basic elevation information for earth science studies and mapping applications in the United States. Scientists and resource managers use NED data for global change research, hydrologic modeling, resource monitoring, mapping and visualization, and many other applications. The NED's Seamless Data Distribution System (SDDS) offers seamless data for a user-defined area, in a variety of formats, for online download or media delivery.

The NED production approach ensures that georeferencing of the layers results in properly nested and coincident data across the three resolutions. In the context of the raster data model used for the NED, the area represented by one elevation post in the 1-arc-second layer is represented by nine elevation posts in the 1/3-arc-second layer, and by eighty-one elevation posts in the 1/9-arc-second layer (Figure 3.4). Where all three resolution layers can be produced, each layer is constructed independently from the same high-resolution source data using an aggregation method appropriate to the grid spacing being produced.

Figure 3.5 shows data from three current NED layers for an area in southern West Virginia. The source data for this area were derived through photogrammetric compilation of mass points and breaklines and subsequent surface generation. Most of the newer 1/9-arc-second data in the NED are from LiDAR.

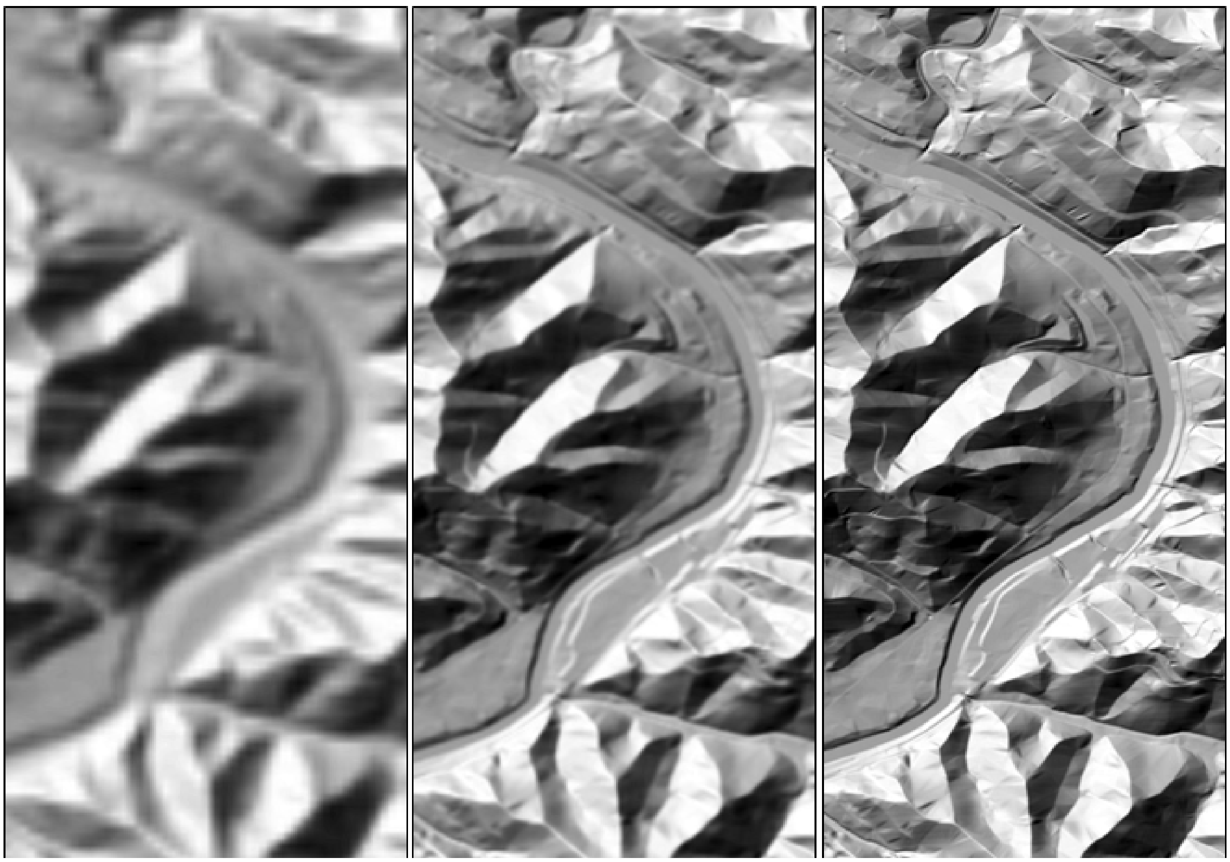


Figure 3.5. Multi-resolution NED layers for an area in West Virginia (1-arc-second data on the left; 1/3-arc-second data in the center; 1/9-arc-second data on the right). These data were derived photogrammetrically.

The following summarizes the demand for NED data online downloads:

- 1-arc-second NED data: there are up to 22,500 online NED downloads per month and 213,011 downloads per year; there are up to 1,150 Gbytes of 1-arc-second NED data downloaded per month and 11,379 Gbytes per year.
- 1/3-arc-second NED data: there are up to 68,000 online NED downloads per month and 259,374 downloads per year; there are up to 2,400 Gbytes of 1/3-arc-second NED data downloaded per month and 19,773 Gbytes per year.

- <u>1/9-arc-second NED data</u>: there are up to 10,000 online NED downloads per month and 44,921 downloads per year; there are up to 830 Gbytes of 1/9-arc-second NED data downloaded per month and 3,205 Gbytes per year. These statistics are growing rapidly with increased availability of 1/9-arc-second data in the NED.
- <u>All NED data</u>: there are approximately 35 terabytes of NED data downloaded per year from approximately a half million annual NED data downloads.

The NEEA addresses the needs for the elevation layer of *The National Map*. High quality 3-D elevation data are critical to a broad range of government and private sector applications such as resource management, infrastructure planning, environmental monitoring, and disaster mitigation. Without high quality 3-D elevation data, FEMA could not create flood risk maps, research scientists could not easily discover new geologic faults that could cause earthquakes, and coastal-area flood inundation assessments would not be possible. For much of the nation, professionals in a broad range of critical fields find themselves lacking the right data to perform their missions. Today, federal agencies, states, local governments, tribes and nongovernmental users (not-for-profit and private businesses) are grappling with maps created from elevation data that are mostly 30-50 years old and far less detailed than is needed. See Figure 3.6.

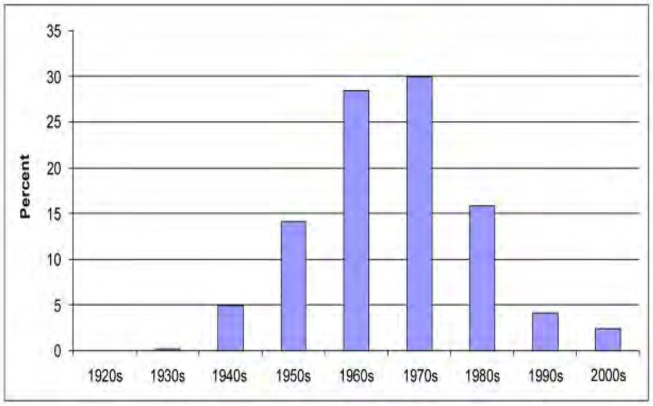


Figure 3.6. Age of topographic map data in the National Elevation Dataset (NED).

Customers of *The National Map* consistently identify elevation data as one of the top three data types needed to address their business requirements; and accurate elevation data are often their No. 1 requirement for success. Mapping systems need elevation data to support 3-D analysis and viewing. In addition, elevation data, geodetic control, and imagery are the fundamental data building blocks of geographic information systems (GIS). Elevation data, when combined with imagery, create a foundation for interpreting or extracting other data, such as transportation, water features and buildings. Without a high quality geospatial foundation, it will not be possible to achieve the vision of an integrated national geospatial data asset to support science and operational decision-making.

The use of elevation data has expanded as new technologies produce very high-resolution landscape models. The term “enhanced elevation” is used to describe precise 3-D measurements of land or submerged topography, built features, vegetation structure, and other landscape detail. LiDAR has become the technology of choice for many of these measurements but radar and other technologies also play an important role. LiDAR datasets can be transformed into a dozen or more information types such as bare earth elevation, slope, top of surface (trees, buildings, etc.) and vegetation structure.

3.4 National Digital Elevation Program (NDEP)

The National Digital Elevation Program (NDEP) is the coordinating body for the NED. The NDEP, which fosters collaboration on elevation data development, is a consortium of federal agencies working together to satisfy multiple elevation data requirements. The states also have a voice in the NDEP through a representative from the National States Geographic Information Council (NSGIC). The NDEP has produced a best practices document titled "Guidelines for Digital Elevation Data" (National Digital Elevation Program, 2004) to help member agencies as they acquire high-resolution elevation data. Data collected with the characteristics discussed in the guidelines meet the requirements of multiple federal agencies, and thus make efficient use of federal funds available for new geospatial data collection. The NDEP also operates a project tracking system whereby information on proposed, planned, in-work, or completed elevation projects is posted and shared; but this process is voluntary and normally incomplete. The project tracking tool is useful for agencies that are seeking partners to acquire data over a specific area. The NED benefits from NDEP activities in that it becomes the repository for bare earth elevation data as projects are completed. In this way, the benefits of data acquired by one agency are extended to other agencies, and eventually to the general user community, through the NED.

Although the NDEP has leveraged limited federal and state agency resources to make progress toward an improved national elevation data resource, a national strategy has not existed with sufficient resources to implement it. The majority of U.S. elevation data are more than 30 years old, coarser than 10-meters in resolution, and do not support current and emerging requirements. This is a major reason why NDEP partners collaborated on the need for this NEEA.

3.5 Center for LiDAR Information, Coordination and Knowledge (CLICK)

A relatively new USGS activity, the Center for LIDAR Information, Coordination and Knowledge (CLICK), is another forum for information exchange and topographic data discovery that benefits the NED. CLICK is a virtual Web-based center with the goal of providing a clearinghouse for LiDAR information and point cloud data. The CLICK Web site (http://LiDAR.cr.usgs.gov) provides a bulletin board with numerous topics related to LiDAR data for discussion among the community, including topics on bare earth data and NDEP. The site also includes a tool for viewing the coverage of available data and downloading point cloud data, in addition to an extensive list of LiDAR-related Web sites and references. Data acquired for distribution through the CLICK are also used as a source of high-resolution bare earth elevation data to enhance the coverage of the NED 1/9-arc-second layer. In addition, through the CLICK, users have access to the full-return point cloud form of LiDAR data that are included in the NED as bare earth gridded elevation data. The CLICK site is very popular (817 downloads, totaling 1.418 terabytes of LiDAR data in September, 2011).

3.6 Elevation Derivatives for National Applications (EDNA)

As a primary source of basic topographic information, the NED is used in numerous applications that require elevation as an input. Elevation data are critically important for many hydrologic studies, and these studies are one of the main uses of the NED and associated derived products. The USGS data set known as the Elevation Derivatives for National Applications (EDNA) is based on the 1-arc-second NED and offers a multi-layered hydrologically-conditioned database that was developed specifically for large-area hydrologic modeling applications. Hydrologic conditioning results in elevation data with improved hydrologic flow representation and allows for derivation of multiple raster and vector layers optimized for hydrologic modeling, including flow direction, flow accumulation, streamlines, catchments, slope and aspect. A primary use of the EDNA layers has been for drainage basin delineation and characterization. Interactive basin delineation based on the EDNA data set is available through Web-enabled tools linked to the EDNA Web site. Current EDNA development includes taking advantage of the higher resolution layers of the NED for improved flow routing. EDNA is a project that never became an official USGS product. Requests for EDNA data come to the USGS EROS by email, and the data are delivered by FTP or external drive on a colleague to colleague basis. For the EDNA Home Web page, the number of monthly "hits" is between 330 and 520. Funding to maintain the EDNA project is also in jeopardy.

3.7 OpenTopography Portal

The OpenTopography Portal is a collaboration between computer scientists at San Diego Supercomputer Center at the University of California, San Diego, and is operated in collaboration with colleagues in the School of Earth and Space Exploration at Arizona State University. Core operational support for OpenTopography comes from the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) to support various research and development activities. OpenTopography was initially developed as a proof of concept cyberinfrastructure in the Earth sciences project as part of the NSF Information and Technology Research (ITR) program-funded Geoscience Network (GEON) project (http://www.geongrid.org/). The mission of the OpenTopography Facility is to:

- Democratize online access to high-resolution (meter to sub-meter scale), Earth science-oriented, topography data acquired with LiDAR and other technologies.
- Harness cutting edge cyberinfrastructure to provide Web service-based data access, processing, and analysis capabilities that are scalable, extensible, and innovative
- Promote discovery of data and software tools through community populated metadata catalogs
- Partner with public domain data holders to leverage OpenTopography infrastructure for data discovery, hosting and processing
- Provide professional training and expert guidance in data management, processing, and analysis
- Foster interaction and knowledge exchange in the Earth Science LiDAR user community

The OpenTopography Portal has three data access levels:

- Google Earth provides an excellent platform to deliver LiDAR-derived visualizations for research, education, and outreach purposes. These files display full-resolution images derived from LiDAR in the Google Earth virtual globe. The virtual globe environment provides a freely available and easily navigated viewer and enables quick integration of the LiDAR visualizations with imagery, geographic layers, and other relevant data available in KML format.
- In many cases, LiDAR datasets are delivered with a set of pre-processed "standard" digital elevation models (DEMs) at an optimal resolution for the dataset. These data are typically delivered as bare earth (ground) and top reflective surfaces organized into tiles (e.g., 1 km^2). The

DEMs are in common GIS formats (e.g., ESRI Arc Binary) and are compressed (zipped) to reduce their size. OpenTopography permits users to download all tiles for an area of interest.

- LiDAR point cloud data and on-demand processing from OpenTopography allow users to define an area of interest, as well as a subset of the data (e.g., "ground returns only"), and then to download the results of this query in ASCII or LAS binary point cloud formats. Also available is the option to generate custom derivative products such as DEMs produced with user-defined resolution and algorithm parameters, and downloaded in a number of different file formats. The system will also generate derivative products such as hillshade and slope maps, and will dynamically generate visualizations of the data products for display in a web browser or Google Earth.

The capabilities and limitations of the OpenTopography Portal, as well as NOAA's Digital Coast, are discussed in Section 7 of this report. Continued funding support for the OpenTopography Portal is uncertain.

3.8 Digital Coast

Digital Coast is both a project and a partnership between the NOAA Coastal Services Center (CSC), the National Association of Counties (NACo), The National States Geographic Information Council (NSGIC), The Nature Conservancy (TNC), the Association of State Floodplain Managers (ASFPM), the Coastal States Organization (CSO), and the American Planning Association (APA). With a large percentage of the population of the United States residing near the coast, these partners deal with a myriad of issues pertaining to conservation of coastal wetlands, protection of developed shores, adapting to new sea levels and severe storms, defending vulnerable regions from coastal flooding, and other challenges to the growth and resiliency of coastal communities. The Digital Coast includes data, tools, training, and actions. Whereas the majority of the data are topographic, both topographic and bathymetric data are critical parts. The CSC contributes topographic LiDAR to USGS for the CLICK site.

In addition to the CSC, many different partners and groups have contributed to the LiDAR data collection housed and distributed by the CSC. The data span more than a decade and were collected using several different topographic and bathymetric LiDAR sensors. Data are available for all of the coastal states and range from shoreline strips to full county coverage. The data were delivered to the CSC in various formats, projections, datums, and units. Once received, the data are reviewed, checked for errors, and standardized by the CSC in a single format, projection, and datum.

NOAA also contracts for data in partnership with state, local and federal partners. While some data are contributed as described above, NOAA has been an active part of the collection partnership for much of the data.

3.9 Ramona GIS Inventory

Ramona is produced by NSGIC as a tool for states and their partners. Its primary purpose is to track the status of GIS data in state and local governments to aid the planning and building of Spatial Data Infrastructures. Ramona is accessed through www.gisinventory.net (nationwide view) or through any individual state-view using the state's 2-letter prefix in the URL (e.g., www.nc.gisinventory.net). Ramona provides contact information but data cannot be downloaded from Ramona.

Ramona was developed to inventory the GIS data holdings of tribal, state and local governments, and their partners. It was intended to provide a single, consistent platform for the nation that is designed to work in concert with The National Map but it can also be customized for use by each State.

3.10 Issues with the Status Quo

As summarized above, there are multiple sites for storage and retrieval of elevation data, but no one site is ideal for all users. Because the USGS is the OMB Circular A-16 lead Agency for terrestrial elevation data, this section will focus on the NED.

The latest NED Release Notes are provided at Appendix A. These notes show that 1-arc-second (30-meter post spacing) and 1/3-arc-second (10-meter post spacing) NED data are now available nationwide, but most of this NED data were compiled from photogrammetric contours produced 30-50 years ago from paper USGS topographic quadrangle maps, and the equivalent contour accuracy depends on the contour intervals used – usually 10 to 20-foot contours. NED data at 1/9-arc-second (3-meter post spacing) are available for only a small portion of the country.

The current state of the Nation's elevation data collection efforts and data availability (the "status quo") can be characterized as follows:

- Federal, state and local agencies seek funding partners for data acquisition.
- Federal, state and local agencies set schedules and Quality Level (QL) requirements, manage contracts, and perform their own quality assurance/quality control (QA/QC) or contract for independent third-party QA/QC.
- Federal, state, and local agencies submit data to USGS for the NED and CLICK (this does not always happen).
- Commercial vendors sell or license products (e.g., IFSAR).
- Private industry manages its own data, which generally is not in public domain, and can sell their data.

The five Quality Levels (QLs) of elevation data were described in Table 1.2 of the Executive Summary. In terms of existing data:

- Approximately 75 percent of the gridded Digital Elevation Models (DEMs) in the NED are old, inaccurate, and lack the high resolution (1-meter) required for today's user applications (most DEMs in the NED have 10-meter resolution).
- The highest quality LiDAR data (QL1) are mostly in small portions of the Pacific Northwest and QL2 LiDAR data are mostly along coasts and scattered elsewhere; these higher resolution datasets currently contribute to 1/9-arc-second DEMs (3-meter post spacing) in the NED only because the NED does not provide 1/27-arc-second (1-meter DEMs).
- Less-accurate QL3 LiDAR data predominate elsewhere, but only about 28.4 percent of the lower 49 states plus Washington D.C. are mapped with LiDAR, and growing at a slow pace of a few percent per year.

- QL5 IFSAR data for 49 states are not in the public domain.
- Approximately 15 percent of Alaska has elevation data at QL5, with only small pockets of LiDAR. Alaska was mapped photogrammetrically at a small scale of 1:63,360 (1" = 1 mile) in the 1950s, but these maps were not produced to National Map Accuracy Standards because of the lack of survey control and other technical limitations. Much larger scale maps are available in the other 49 states.
- Very few of the elevation derivative products required by consumers are available, even though the majority of users require hydro-enforced Digital Terrain Models (DTMs), Digital Surface Models (DSMs), contours, hillshades, slope and aspect maps, for example; and users literally duplicate their efforts whenever two or more users generate their own elevation derivatives of the same area.

Disadvantages of the Status Quo

Major disadvantages of the status quo are:

- Regardless of Quality Level, acquisition costs per square mile are higher in most cases when acquired in small, irregularly-shaped areas, as at present.
- A few federal agencies have the expertise to write appropriate technical specifications, clear and unambiguous Scopes of Work, and perform complex QA/QC tasks prior to acceptance of data. When less-experienced federal, state and local governments perform their own contracting for LiDAR or IFSAR, for example, costs are typically higher and there is normally a higher rate of dissatisfaction with products received. Several states have discovered that their elevation data were not accepted for inclusion in the NED because the data failed to meet minimum NED standards.
- Adjoining elevation datasets may be inconsistent and incompatible with each other when acquired by different contracts, using different specifications. It is not uncommon to have elevation differences of two feet along county and/or state boundaries, especially when datasets are produced to different standards.
- At the current collection rate of a few percent per year, nationwide coverage of reasonably consistent enhanced nationwide dataset is unlikely in less than 35 years, and some states may never get the mission-critical data needed by federal, state, local and nongovernmental users.
- When elevation-derived products are not provided to the public, communities of use may duplicate efforts to create similar products.
- Users have trouble finding elevation data, and the data may not meet requirements once found.
- Some states, counties, consortia, and private organizations acquire their own LiDAR data to meet their own priorities, and they may or may not share their plans with the NDEP or NSGIC which operate project tracking systems on proposed, planned, in-work, or completed elevation projects.

What is needed

This NEEA report will show that users broadly require enhanced elevation data and derivatives nationwide with higher accuracy, higher resolution, greater currentness, and produced to common standards and guidelines.

Although there are approximately a half million online data downloads annually from the NED, the differences between "what users have" and "what users need" are summarized in Table 3.2.

Table 3.2. Issues with the National Elevation Dataset (NED)

What users have	What users need
Currently, approximately 28.4% of the lower 49 states and D.C. has LiDAR data, and approximately 15.2% of Alaska has IFSAR data; nationwide, enhanced elevation datasets are growing at a slow annual rate and some states might never be mapped	Total U.S. coverage with enhanced elevation data
Most DEMs in the NED were produced from old quad maps accurate to 5-10 feet at the 90% confidence level	Most Business Uses require DEMs accurate to 6-12 inches at the 90% confidence level
Most DEMs in the NED have 1/3-arc-second (10-meter) post spacing	Users require high-resolution DEMs nationwide with 1/27-arc-second (1-meter) post spacing
Most DEMs in the NED were produced from quad maps 30-50 years old	Users require current DEMs nationwide with update frequencies no greater than 10 years.
Hydro-flattened DEMs in the NED where bridges and culverts impede the flow of water in hydrologic models	Users require both hydro-flattened and hydro-enforced DEMs where bridges/culverts are "cut" so DEMs model the actual flow of water
All DEMs in the NED are bare-earth gridded Digital Terrain Models (DTMs) of the bare-earth terrain	Users require both gridded DTMs and Digital Surface Models (DSMs) of tree tops, roof tops, towers, etc.
No contours or hillshades are provided	Contours and/or hillshades are required
From USGS' Elevation Derivatives for National Applications (EDNA), some slope and aspect data are available from low resolution DEMs (30-meter post spacing)	Some users require nationwide slope and aspect data from higher resolution DEMs (3-meter or 1-meter post spacing)
LiDAR point cloud data are partially provided by USGS' CLICK site which has unstable resourcing	Many users require reliable comprehensive access to LiDAR point cloud data that supports diverse applications analysis of above ground features including vegetation structure
Poor metadata where currency, accuracy and data production methods are often unknown	All users require good metadata where currency, accuracy and data production methods are well documented
Inadequate data discovery mechanisms to know what data are available nationwide and plans for future acquisitions and partnerships	Most users require improved data discovery mechanisms to support increased partnering among federal, state and local agencies
Elevation data acquired by state and local governments are often nonstandard and cannot be entered in the NED; some datasets are proprietary and not in the NED	All users require common Guidelines and Specifications so that data acquired by diverse federal, state and local governments is more consistent, and is more useful for updating the NED

4. Information Gathering Methodology

4.1 Project Management Plan

Dewberry worked closely with USGS in developing a detailed Project Management Plan for the NEEA. This plan was coordinated with and approved by project sponsors from USGS, NGA, FEMA, NRCS, NOAA and a representative of the NDEP. This plan included the following major components:

1. Documentation of roles, responsibilities and procedures for collection of Business Use *mission-critical* requirements and benefits and inventory of existing and planned elevation data. Dewberry was responsible for collection of Business Use requirements and benefits from federal agencies, using Points of Contact (POCs) provided by USGS, as well as selected nongovernmental organizations (not-for-profit and private companies). Using its network of Geospatial Liaisons, USGS was responsible for collection of Business Use requirements and benefits from state POCs as well as some regional, county, local and tribal governments. USGS was also responsible for providing Dewberry with an inventory of existing elevation datasets, and those programmed for collection, that could satisfy Business Use *mission-critical* requirements.

2. Documentation of Task 1 plans and/or procedures for collecting requirements and benefits for 27 pre-defined Business Uses, using Functional Activities to be defined by each POC in their own words. This included plans for kick-off meetings with federal POCs and USGS Geospatial Liaisons; completion of online questionnaires (Appendix J, via Survey Monkey™) by selected managerial and technical user respondents; procedures for follow-on interviews and workshops, with POCs and key managers, to include a sample Workshop Guide; procedures for POC validation of Business Use and Functional Activity requirements and benefits from federal, state, local and tribal governments and nongovernmental organizations; and development of a geodatabase required for efficient and fully geo-enabled Benefit Cost Analyses. The online survey was approved by the Office of Management and Budget for surveying non-federal organizations, and the online questionnaire was linked to a SharePoint site with answers to frequently asked questions (FAQs) and examples of different types of user benefits from elevation data.

3. Documentation of Task 2 plans for aggregation and analyses of Business Uses. This included plans for aggregation and analysis of mission-critical user requirements for enhanced elevation data, and benefits of receiving such data for Functional Activities that support each of the 27 major Business Uses. Plans for a Benefit Cost Analysis include the aggregation of $/Mi2 benefits from hundreds of Functional Activities for each 1-degree cell (1-degree latitude by 1-degree longitude) compared with the $/Mi2 cost of data by Quality Level and update frequency to determine the optimum Quality Level and update frequency for each 1-degree cell so that enhanced elevation data, regardless of Quality Level and update frequency, can be acquired in a most cost-effective manner.

4. Documentation of Task 3 plans for evaluation of emerging data collection technologies and related technical issues. This included evaluation of emerging topographic LiDAR technology; IFSAR technology; bathymetric LiDAR technology; and technical issues that could impose a risk to potential program implementation scenarios.

5. Documentation of Task 4 technology and enterprise IT infrastructure alternatives for providing access to national elevation data and derivative products. All alternatives included centralized data storage and hosting infrastructure. These alternatives also included potential private/public partnerships. Dewberry met with representatives of the EROS Data Center, NOAA Coastal Services Center, and the OpenTopography Portal to get information on best practices for storing and hosting LiDAR and derived elevation data. Dewberry met with USGS and other agency representatives to understand technical strategies, preferences and limitations. Dewberry did not provide technical IT infrastructure consulting because that is beyond the scope of Dewberry contract with USGS for Geospatial Products and Services.
6. Documentation of Task 5 development and evaluation of implementation scenarios on how enhanced elevation data could best be served to the public.
7. Schedule for completion of various tasks and submission of deliverables to USGS.
8. POC instructions and risk management strategies.

Before the Project Management Plan could be developed by Dewberry, numerous working meetings were held with USGS to define terms such as *mission-critical*, *Business Uses*, *Functional Activities*, data *Quality Levels*, and data *update frequencies*. *Mission-critical* was defined as “indispensable for mission accomplishment and/or essential for effective/efficient operations in accomplishing the core mission of the organization.” It was agreed that the assessment should not be bogged down by nice-to-have requirements that were not mission-critical. *Business Use* was defined as the ultimate use of services or products from Functional Activities to accomplish an organizational mission within 27 pre-defined major Business Uses. *Functional Activity* names were not pre-defined but described by POCs in their own words to explain their organization’s activity or process that requires enhanced elevation data to accomplish a Business Use. The Business Uses and data Quality Levels are listed below.

The 27 pre-defined Business Uses are named in Table 4.1.

Table 4.1. The 27 pre-defined Business Use (BU) numbers and names

1. Natural resources conservation	15. Sea level rise and subsidence
2. Water supply and quality	16. Wildfire management, planning and response
3. River & stream resource management	17. Homeland security, law enforcement, and disaster response
4. Coastal zone management	18. Land navigation and safety
5. Forest resources management	19. Marine navigation and safety
6. Rangeland management	20. Aviation navigation and safety
7. Wildlife and habitat management	21. Infrastructure and construction management
8. Agriculture and precision farming	22. Urban and regional planning
9. Geologic resource assessment and hazard mitigation	23. Health and human services
10. Resource mining	24. Real estate/banking/mortgage/insurance
11. Renewable energy resources	25. Education K-12 and beyond
12. Oil and gas resources	26. Recreation
13. Cultural resources preservation and management	27. Telecommunications
14. Flood risk management	

The five pre-defined Quality Levels of topographic data are summarized in Table 4.2, and the five update frequencies were identified as: (1) annual updates; (2) every 2-3 years; (3) every 4-5 years; (4) every 6-10 years; and (5) greater than 10 years, assumed to be 11-20 years. Respondents could also specify "event driven" requirements not regularly scheduled.

Table 4.2. The five pre-defined topographic data Quality Levels (QLs)

Elevation Quality Levels (QL)	Source	Horizontal Resolution Terms			Vertical Accuracy Terms	
		Point Density	Nominal Pulse Spacing (NPS)	DEM Post Spacing	Vertical RMSEz	Equivalent Contour Accuracy
QL 1	LiDAR	8 pts/m^2	0.35 m	1/27 arc-sec ~1 meter	9.25 cm	1-ft
QL 2	LiDAR	2 pts/m^2	0.7 m	1/27 arc-sec ~1 meter	9.25 cm	1-ft
QL 3	LiDAR	1 – 0.25 pts/m^2	1 – 2 m	1/9 arc-sec ~3 meters	≤18.5 cm	2-ft
QL 4	Imagery	0.04 pts/m^2	5 m	1/3 arc-sec ~10 meters	46.3 cm – 139 cm	5 – 15 ft
QL 5	IFSAR	0.04 pts/m^2	5 m	1/3 arc-sec ~10 meters	92.7 cm – 185 cm	10 – 20 ft

As summarized in Table 4.2, each of the five designated topographic data Quality Levels is considered "enhanced" because each is superior in one way or another to the current patchwork of data in the NED summarized in Appendix A. The quality levels are described as follows beginning with QL5. Expanded technical details on topographic and bathymetric LiDAR, as well as IFSAR, are provided in Appendix G.

Interferometric Synthetic Aperture Radar (IFSAR) (QL5)

QL5 IFSAR is the least accurate of the five Quality Levels considered for the NEEA, but it is also the least expensive. NEXTMap® USA IFSAR datasets from Intermap Technologies, Inc. are available for licensing in 49 states (all except Alaska) in the form of DTMs, DSMs and ortho-rectified radar imagery (ORI) but they are not currently available in the public domain. Existing NEXTMap® USA data, currently 2 to 6 years old, could be placed in the public domain at a relatively low cost (<$16/mi^2), subject to negotiation; new IFSAR data acquisitions of large areas would cost an estimated $80/mi^2 in the lower 49 states and $94.50/mi^2 in Alaska, including independent QA/QC. QL5 IFSAR data are required by the Federal Communications Commission (FCC), Environmental Protection Agency (EPA), Federal Aviation Administration (FAA), NOAA, and FEMA and others for selected Functional Activities. In Alaska, IFSAR data are also required by the Bureau of Land Management (BLM), National Park Service (NPS), Fish and Wildlife Service (F&WS), U.S. Forest Service (USFS), Natural Resources Conservation Service (NRCS), Federal Energy Regulatory Commission (FERC), and others.

With the possible exception of dense forests, QL5 IFSAR is considered superior to the NED because it is more-accurate overall, is more up-to-date, and is more-consistent and seamless for the lower 49 states. About 15% of Alaska is currently mapped with IFSAR. IFSAR has a technical advantage in Alaska because IFSAR data are acquired day/night and all weather, mapping through darkness, clouds and fog under the most severe of conditions in remote areas. Figure 4.1 shows an IFSAR aircraft with radome. Figures 4.2, 4.3 and 4.4 show standard IFSAR products – ORI, DTM and DSM, respectively.

Figure 4.1. IFSAR elevation differences are reconstructed from the phase difference between radar signals arriving at two antennae, with known offsets, housed in the radome.

Figure 4.2. Ortho-rectified Radar Image (ORI) is a standard black/white image product of IFSAR. Water returns are black and thus helpful in hydro-enforcement of DTMs.

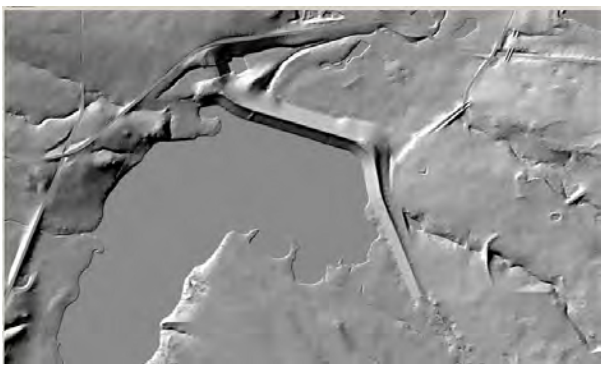


Figure 4.3. Digital Terrain Model (DTM) of the bare-earth terrain, hydro-enforced with the help of ORI imagery that clearly delineates water areas

Figure 4.4. Digital Surface Model (DSM) that directly maps the top reflective surfaces of treetops, rooftops, etc.

Stereo Airborne Imagery (QL4)

DTMs and DSMs can be produced from stereo aerial imagery acquired by federal, state and local governments for production of digital orthophotos. Airborne stereo imagery, already acquired for other purposes, can be re-used, along with its Aerial Triangulation (AT) data, to produce DSMs and DTMs that are more accurate and current than DEMs in the NED. The accuracy and DEM post spacing is largely variable as a result of different flying heights and control procedures used to produce orthophotos with pixel resolutions varying from 3 inches to 2 meters. For example, some photogrammetric DEMs could be produced with 2-foot contour accuracy, whereas DEMs produced from imagery from the National Agricultural Imagery Program (NAIP) have been produced with 15-foot contour accuracy. DEMs at Quality Level 4 can also be produced from Light Detection and Ranging (LiDAR), but these would be below today's industry standard products. DEMs can also be produced from stereo satellite imagery, but the accuracy is poorer than QL5. QL4 DEMs produced from existing stereo images are considered superior to DEMs in the NED because the data are more current, more accurate, and should not require new aerial data acquisition. However, very few requirements for QL4 data were documented in the NEEA.

Figure 4.5 illustrates a Leica ADS40 pushbroom camera that looks forward, downward and backward, collecting panchromatic and multispectral (R/G/B and near-infrared) imagery at hundreds of lines of 12,000 pixels every second. The triple image matching is used for triangulation and DSM generation, providing robust 3-D solutions. Triangulation includes automatic measurement of tie points and interactive measurement of control points. The "pushbroom" produces seamless strips of raw (Level 0), rectified (Level 1) and orthorectified (Level 2) imagery such as shown at Figure 4.6. There are also many forms of digital frame cameras that acquire panchromatic and multispectral images with large block coverage per image, similar to conventional 9" x 9" photos that have been digitized but far superior in terms of spectral response. Digital imagery from digital frame cameras or pushbroom cameras, typically used to produce digital orthophotos, can also be used for stereo compilation of DEMs and/or breaklines. It would be rare to acquire such imagery for the sole purpose of producing DEMs or breaklines, but once the imagery is acquired and aerial triangulated for production of digital orthophotos, it is possible to re-use existing imagery for production of DSMs, DEMs and/or breaklines (see Figures 4.7 and 4.8). The accuracy of these elevation products is variable, depending on flying height, survey control, aerial triangulation procedures, and other parameters.

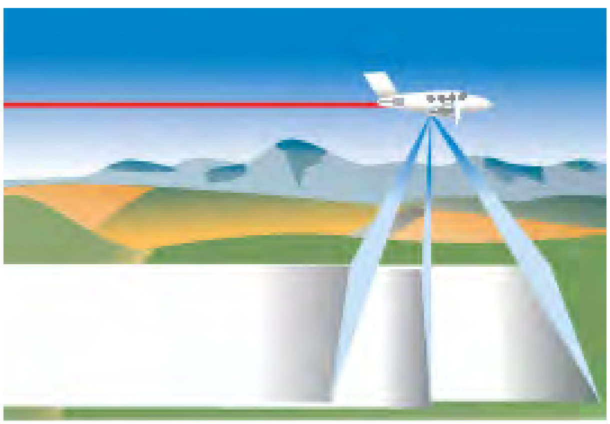


Figure 4.5. An ADS40 pushbroom camera that creates its own stereo views with arrays that look forward, downward, and backward as the plane flies over the terrain.

Figure 4.6. A digital orthophoto produced from stereo imagery. Either pushbroom or frame mapping cameras are ideal for digital orthophoto production. Although this is B/W, most orthophotos are full color or color infrared.

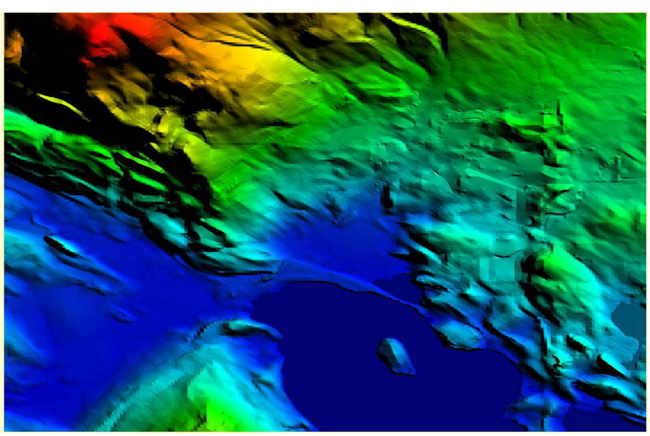


Figure 4.7. A gridded DEM produced from stereo image auto-correlation.

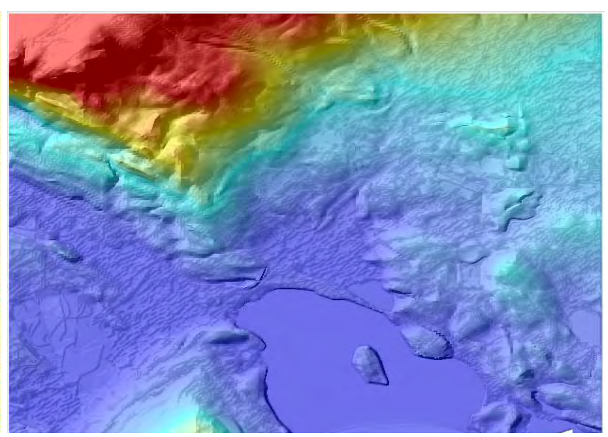


Figure 4.8. Hillshades are produced with different look angles and different sun angles. This includes manual breaklines from photogrammetry for hydro-enforcement of water edges.

Airborne Topographic Light Detection and Ranging (LiDAR) (QL3, QL2, QL1)

Airborne topographic LiDAR is an active, airborne remote sensing technology that combines ranges from a near-infrared laser (wavelength = 1064 nm), scan angles, post-processed position and orientation data from an integrated GPS/IMU (Inertial Measurement Unit) system, and calibration data to generate dense, accurate, irregularly-spaced 4-D (x/y/z and intensity) point data called "point clouds." The point clouds can be used to create irregularly-spaced DTMs and DSMs, regularly-spaced DEMs, as well as breaklines and contours, and used for many different types of 3-D modeling including hydrologic and hydraulic models, building models, canopy models, etc. Figure 4.9 shows an example of a LiDAR intensity image that also shows unreliable returns on water surfaces. Figure 4.10 shows how irregularly-spaced mass points are used to create a gridded DEM as well as breaklines of linear features. Figure 4.11 shows a dense forest canopy that appears to be impenetrable, but Figure 4.12 shows how LiDAR succeeded in mapping the bare-earth terrain beneath the dense canopy. This is the major benefit of LiDAR because neither IFSAR nor imagery can accurately map the bare-earth terrain beneath dense vegetation.

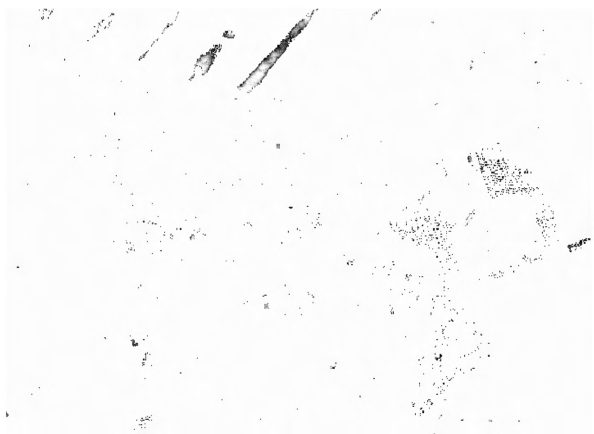


Figure 4.9. LiDAR intensity image showing high reflectance along the nadir of flightlines with no reflectance off-nadir. Topographic LiDAR returns on water are known to be unreliable.

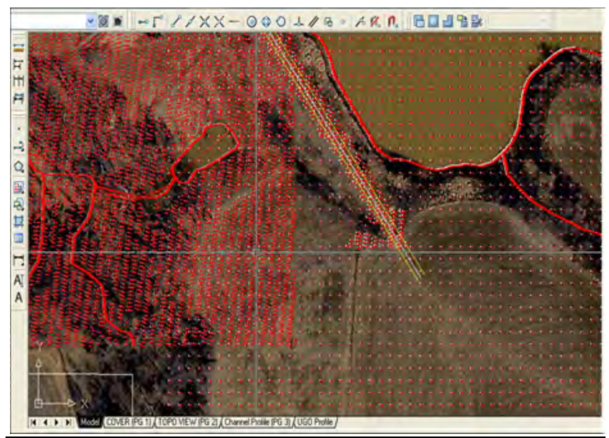


Figure 4.10. LiDAR nominal pulse spacing (on left) must be denser than the uniformly gridded DEM post spacing (on right), interpolated from the dense irregular points. Breaklines are produced from LiDARgrammetry.

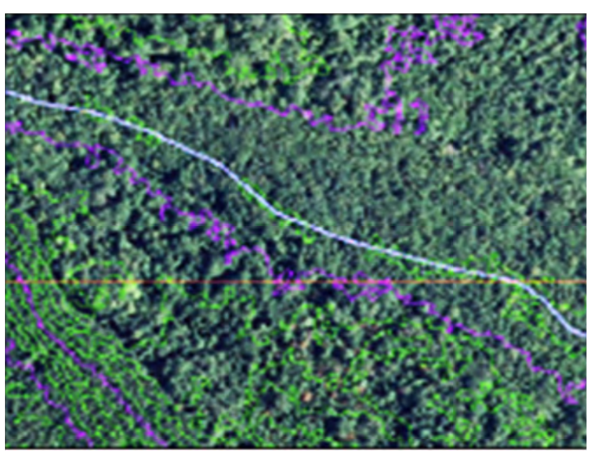


Figure 4.11. Orthophoto makes dense Florida vegetation look impenetrable; but LiDAR mapped DTM with Quality Level 2 LiDAR (2 points/m^2), with 50% sidelap between flightlines.

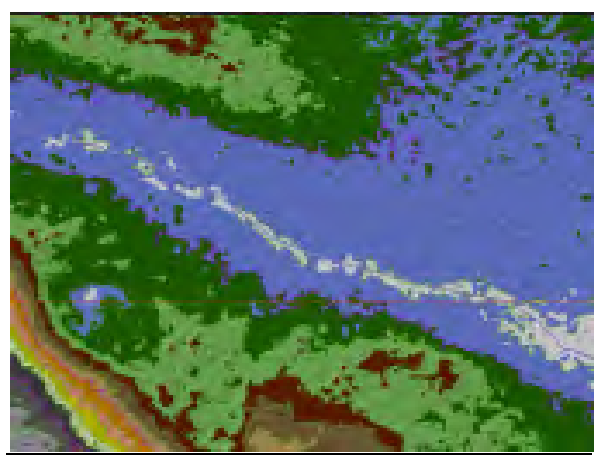


Figure 4.12. Color-coded 1-foot contours, produced from the DTM, show dry depression contours and hydro flow line. The 50% sidelap provided average point density of 4 points/m^2.

Quality Level 3 LiDAR. Most legacy LiDAR data acquired during the past decade have been acquired at QL3. USGS' current *LiDAR Base Guidelines and Specifications*, v.13 (see Appendix I), are considered to be QL3 because they are better than 2-ft equivalent contour accuracy but not accurate enough for 1-ft equivalent contour accuracy specified for QL2 data. Where available for limited geographic areas, some of the very best data in the NED today includes DEMs produced from LiDAR data of QL3; and some LiDAR datasets provided to USGS are maintained in its CLICK site described above.

Quality Level 2 LiDAR. LiDAR data at QL2 are typically acquired because of the need for higher accuracy (1-ft equivalent contour accuracy) and higher point density in coastal areas and flat floodplains. Many Business Uses identified in this assessment require QL2 LiDAR for improved accuracy and/or density.

Quality Level 1 LiDAR. LiDAR data at QL1 are typically acquired because of the need for higher LiDAR point density data in forests and areas of dense vegetation such as mangrove and sawgrass. For example, this Quality Level is critical for determination of forest and individual tree metrics, geologic mapping and geologic fault detection and analyses.

Helicopter-based LiDAR and ground-based Mobile Mapping LiDAR systems yield accuracy and point density even higher than QL1. They are popular for extremely accurate 3-D mapping of highway and transmission line corridors, for example. Tripod-mounted terrestrial LiDAR systems are popular for applications such as extremely accurate 3-D mapping of individual sites and in specialized ecological and earth science studies. These technologies were not within the scope of this NEEA assessment, which focused on airborne remote sensing for a national scale elevation program, rather than project-specific needs that are ground-based and not nationwide.

Airborne Bathymetric LiDAR

Three Quality Levels were also predefined for bathymetric LiDAR: (1) standard Quality Level for bathymetric LiDAR with point spacing between 3 and 5 meters and a vertical RMSE accuracy of approximately 20 cm; (2) coarser resolution or lower accuracy; and (3) higher resolution or accuracy. Bathymetric LiDAR is similar to topographic LiDAR but uses a 532 nanometer blue-green laser instead of a 1064 nanometer infrared laser. The blue-green laser can penetrate water whereas the infrared laser pulses are absorbed at the water surface and provide unreliable water surface elevation values. Some topographic-bathymetric (topo-bathy) LiDAR systems operate with two lasers at these two wavelengths. However, success is not guaranteed when waters are sometimes turbid, and sometimes clear, and when turbidity conditions cannot be predicted in advance.

Many questionnaire respondents were apparently unaware of the limitations of bathymetric LiDAR, which works only in clear water. In many cases requirements were located in areas where bathymetric LiDAR cannot operate, such as in turbid waters that can only be successfully surveyed with sonar, manual stream surveys or other methods beyond the scope of the NEEA. However, bathymetric LiDAR requirements from USGS, NOAA, and the Corps of Engineers did focus on Business Uses that could be satisfied by bathymetric LiDAR.

Figure 4.13 shows bathymetric LiDAR data of the Dry Tortugas National Park, FL, color-coded to show variable submerged area depths and small land areas. Figure 4.14 shows a combined topo-bathy elevation surface at Shilshoal Bay, WA. Bathymetric LiDAR only works where waters are clear, mapping to about two times the Secchi depth, an intuitive water clarity measure that is the depth at which a standard black and white disc, deployed over the side of a boat, is no longer visible to the human eye. Where turbid, navigable waters are deeper than two times the Secchi depth, multi-beam or single-beam sonar is used, as shown at Figure 4.15. When waters are not navigable, then land survey procedures are used, as shown at Figure 4.16. Both sonar and land surveys are beyond the scope of this assessment.

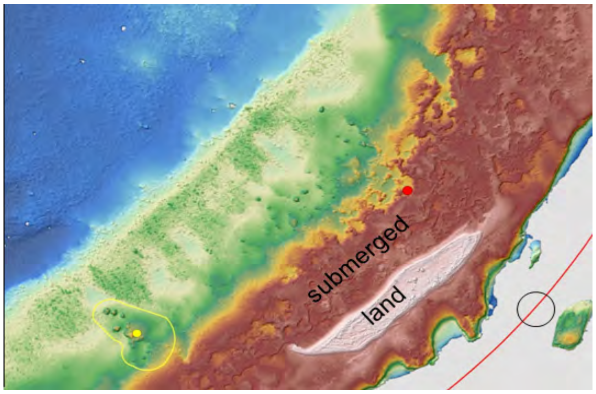


Figure 4.13. Bathymetric LiDAR data of Dry Tortugas National Park, FL, from a blue-green laser that maps submerged surfaces to approximately 2 times the Secchi depth.

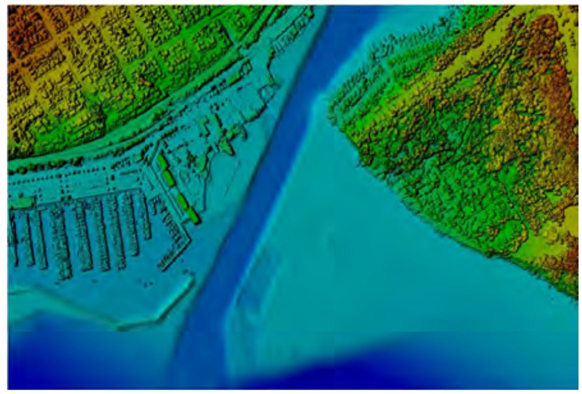


Figure 4.14. Combined topographic LiDAR and bathymetric LiDAR data of Shilshoal Bay, WA, with infrared and blue-green lasers to map both the topographic and bathymetric surfaces in clear water.

Figure 4.15. Small vessel with sonar that maps bathymetric surfaces in navigable waters that are either clear or turbid.

Figure 4.16. Land surveyor surveying stream cross sections in non-navigable waters with conventional survey procedures.

4.2 Questionnaire Process

Dewberry prepared an online questionnaire (conducted via Survey Monkey™) that identified 27 major Business Uses, five topographic data Quality Levels and three bathymetric data Quality Levels summarized above. The questionnaire (see Appendix J) was linked to answers to Frequently Asked Questions (FAQs). To separate *true requirements* from *nice-to-have wishes*, the questionnaire provided instructions for identification of *mission-critical* requirements, defined as "indispensable for mission accomplishment and/or essential for effective/efficient operations in accomplishing the core mission of the organization." Rather than using the questionnaire approach to simply solicit a maximum number of responses, federal and state Points of Contact (POCs) were selected and tasked to identify a selected list of those technical and managerial personnel that would be best positioned to respond to the questionnaire. State POCs included state Geographic Information System (GIS) Coordinators where available. Although 27 Business Uses were established, questionnaire respondents were asked to summarize their organization's Functional Activities in their own words and to explain, for each Functional Activity, what elevation data are needed by Quality Level, where it's needed, why it's needed, how it's used, and the recommended frequency of elevation data update. A total of 358 questionnaire responses were received from Federal agency representatives, plus 363 questionnaire responses from state and local government representatives, including tribes.

4.3 Interview/Workshop Process

The federal and state requirements and benefits data were collected through the survey process that included online questionnaires (described above) followed by workshops with the questionnaire respondents and other managers and content experts from the participating agencies. During the workshops, the requirements and benefits data were refined, consolidated, and validated. Data collected from local governments (county, city, and regional) and tribal governments were also collected by online questionnaires. These results were not reviewed and validated in workshops and are being reported as received. The data received from not-for profit and industry organizations were collected in interviews with those organizations. Overall, there is some variability in the completeness of the responses provided. A considerable portion of respondents (over half) were unable to estimate, quantify or model the expected dollar benefits to their organizations, or the dollar benefits of improved services (based on better elevation data) to their immediate customer sectors or the broader user community including the public. Without supplemental information, the local government information is likely to be insufficient in quantity to allow statistical extrapolation to local governments on a national basis, and was not used in the benefit cost analyses. Appendices B through E list the results from all participating organizations. The total benefits listed in Appendix E cannot be fully realized unless each Functional Activity receives the required Quality Level and update frequency, or better. It cannot be assumed that all customer needs would be met by a national program optimized to collectively satisfy hundreds of different Functional Activities with differing requirements.

4.4 Data Validation Process

A total of 458 Functional Activities were documented and validated by designated Points of Contacts (POCs) for use in the Benefit Cost Analyses. An additional 144 Functional Activities from local and Tribal governments were documented but not included in the Benefit Cost Analyses because these organizations did not have a sufficiently large sample to support benefit extrapolations to the national level. Requirements and benefits were validated by POCs specified for each organization, including requirements by geographic area, Quality Level and update frequency for each Functional Activity identified with *mission-critical* requirements for enhanced elevation data.

Appendix B documents 104 Functional Activities from 34 federal agencies. Appendix C documents 329 Functional Activities from 50 states, 73 Functional Activities from 57 counties, 34 Functional Activities from 22 regional governments, 23 Functional Activities from 17 cities and towns, and 14 Functional Activities from 11 tribes. Appendix D documents 25 Functional Activities from one not-for-profit organization and 12 private companies from key industry sectors. These Appendices provide information used for Dewberry's aggregation and analysis of Business Uses in Appendix E and the geodatabase.

In a few cases, key managers determined that enhanced elevation data were desirable but were not *mission-critical*. The Bureau of Land Management (BLM) and the National Telecommunications and Information Administration (NTIA) indicated that the current NED was acceptable for their major Business Uses. A detailed validation process was conducted prior to agency submission of their Business Use requirements and benefits (summarized in Appendices B, C and D).

4.5 Master Geodatabase

The NEEA assessment had the goal of determining the elevation data needed by users (including the Quality Level and the update frequency of this data) by geographic area, as well as the benefits these users would realize if these data were provided. This information was captured as a geographic dataset, where each record contained a unique Functional Activity, Quality Level, update frequency, and geographic boundary representing the area within which the data are needed.

This information was then used to develop alternative scenarios for collecting national datasets at various costs and producing various levels of benefits.

These data were entered into a geodatabase for each of the Functional Activities. Each Functional Activity has one record per Quality Level of required elevation data. The data recorded in the geodatabase corresponds to the information provided about the elevation Quality Level and update frequency requirements as well as detailed information regarding uses and benefits, both tangible and intangible, for each Functional Activity. All requirements and benefits from federal, state, and county governments, as well as other not-for-profit and private companies were entered into this geodatabase. Data provided by cities/towns, regional and tribal governments were not included in the master geodatabase, but were instead provided in an Excel spreadsheet containing the same attribute information. The information contained in the geodatabase corresponds to tabular information provided in Appendices B, C, and D.

Because the master geodatabase contains one record for each Functional Activity per Quality Level of required elevation data, for Functional Activities with requirements for multiple Quality Levels, the dollar benefits were divided and allocated among the Quality Levels. This was done on a case-by-case basis, taking into consideration the nature of the Functional Activity and the spatial area of the requirement. For instance, for Functional Activities that included the lower 48 states and Alaska, where the lower 48 required LiDAR data and Alaska required IFSAR data, different ratios were used to apportion the dollar benefits. Depending on the Functional Activity, the Alaska share varied from as small as 0.7 percent for EPA's Environmental Protection Functional Activity to as large as 16.2 percent for NOAA's Coastal Mapping and Modeling Functional Activity and for the anonymous oil and gas company's Oil and Gas Operations Functional Activity. On the other hand, for the FEMA Flood Risk Analysis Functional Activity, it was assumed that all of the benefits would accrue to Quality Level 3 LiDAR because FEMA attributed all savings to reduced costs for FEMA's own LiDAR acquisition activities.

As described in Section 5 below, all data were aggregated and analyzed by large, rectangular 1-degree by 1-degree cells. The Functional Activity polygons in the geodatabase were intersected with this 1-degree grid, and square mileage and cumulative benefits were calculated per cell based on this intersection. Figure 4.17 shows this 1-degree grid for the 48 conterminous states and Figure 4.18 shows this 1-degree grid for Alaska. Such grids were not used for Hawaii and U.S. territorial islands.

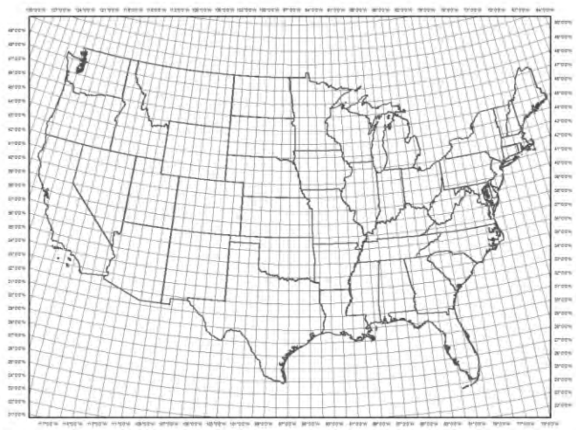


Figure 4.17. 1-degree grid of 48 conterminous states, includes 947 1-degree cells

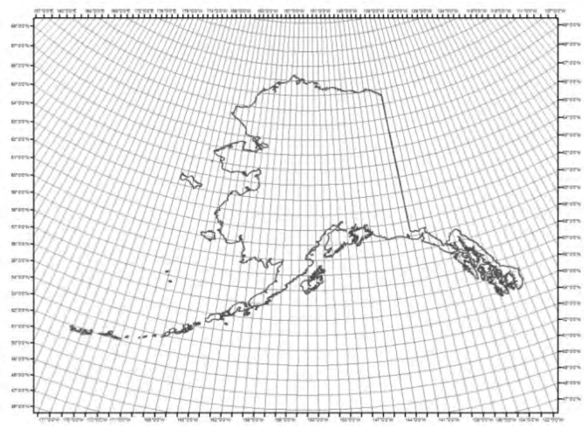


Figure 4.18. 1-degree grid of Alaska, includes 401 1-degree cells, each with smaller areas because of northern latitudes.

Data Dictionary

The data dictionary for the master geodatabase is as follows:

Table 4.3. Data Dictionary for the Master Geodatabase of Business Use Requirements and Benefits

Field Name	Description	Field Definition
OBJECTID	Unique system defined ID	ObjectID
FunctionalActivityID	User defined Functional Activity ID	Double
OrganizationName	Organization name	Text, 100
OrganizationDept	Organization department	Text, 100
OrganizationType	Organization type	Text, 50
Program	Name of program supported by elevation data	Text, 100
ProgramBudget	Estimated program budget supported by elevation data	Double
BusinessUse	Primary Business Use	Text, 100
FunctionalActivity	Functional Activity name	Text, 100
TopoQualityLevel	Required elevation data Quality Level	Text, 50
BathyQualityLevel	Bathymetric Quality Level	Text, 50
BathyIHOStandard	Bathymetric IHO standard	Text, 50
TideCoordinated	Tide coordinated	Text, 50
UpdateFrequency	Required update frequency	Text, 30
OpsBenefitTimeCost	Operational time/cost benefits internal to organization	Text, 20
OpsBenefitImpMissComp	Operational mission compliance benefits internal to organization	Text, 20

OpsBenefitDollars	Operational dollar benefits internal to organization	Double
CSBenefitPerform	Customer service performance benefits	Text, 20
CSBenefitTime	Customer service timeliness benefits	Text, 20
CSBenefitDollars	Customer service dollar benefits	Double
CSBenefitExperience	Customer service customer experience benefits	Text, 20
OtherBenefitSocial	Other public/social benefits	Text, 20
OtherBenefitEnviro	Other environmental benefits	Text, 20
OtherBenefitPolitical	Other strategic/political benefits	Text, 20
OtherBenefitOther	Other benefits	Text, 20
TILEID	ID of 1-degree cell	Double
SqMiles	Square miles of Functional Activity	Double
BenefitsSqMile	Benefits per square mile	Double
SubsetSqMile	Area of Functional Activity per 1-degree cell	Double
SubsetBenefits	Benefits per square mile of Functional Activity within 1-degree cell	Double

Additional attributes were added to the master geodatabase as further analyses were conducted. This schema represents the basic starting point for the Benefit Cost Analyses.

The cost calculations and benefits calculations were performed outside of the geodatabase in an Excel spreadsheet. The spreadsheet contains the TILEID field, allowing the data to be joined to the geodatabase for spatial analysis. The spreadsheet includes rows for all of the 1-degree tiles used for the Benefit Cost Analyses as well as columns for all 25 Quality Level and update frequency combinations considered in the Benefit Cost Analyses. Use of this spreadsheet allowed the cost benefit calculations to be performed efficiently, while still allowing all of the results to be reviewed spatially.

The master geodatabase enabled the requirements and benefits to be viewed and analyzed spatially. Additionally, for each square mile, dollar benefits were aggregated for all Functional Activities as a function of Quality Level and update frequency, among other factors.

4.6 Data Inventory

USGS provided Dewberry with an inventory of known enhanced elevation data available primarily in the public domain. These data were provided to help determine which requirements are already satisfied by existing data, or data in the pipeline for future acquisition and production. Several federal agencies have attempted to collect and manage elevation inventories, but no single source provided a comprehensive picture of data availability. Significant effort was made by USGS Geospatial Liaisons on a state by state basis, to synthesize, normalize and update elevation inventory sources from FEMA, NOAA, NRCS and USGS, creating a consistent inventory for purposes of the assessment. Because of differences in purpose and use, melding the inventory sources required considerable processing to fill attribute gaps, de-conflict records, update attributes and shapefiles and validate the final data inventory.

Figures 4.19 and 4.20 were provided by USGS. Figure 4.19 maps the inventory of enhanced elevation data at all Quality Levels, including projects in progress and funded projects. Approximately 28.4 percent of the lower 49 states and Washington D.C. are already mapped or soon will be mapped with LiDAR, primarily QL3, but with some QL1 LiDAR in the Pacific Northwest. It should be noted that North Carolina (the first state to acquire statewide LiDAR), North Carolina is shown in Figure 4.19 as having QL4 data because the LiDAR vertical accuracy and horizontal resolution are poorer than specified for QL3 LiDAR in Table 1.2.

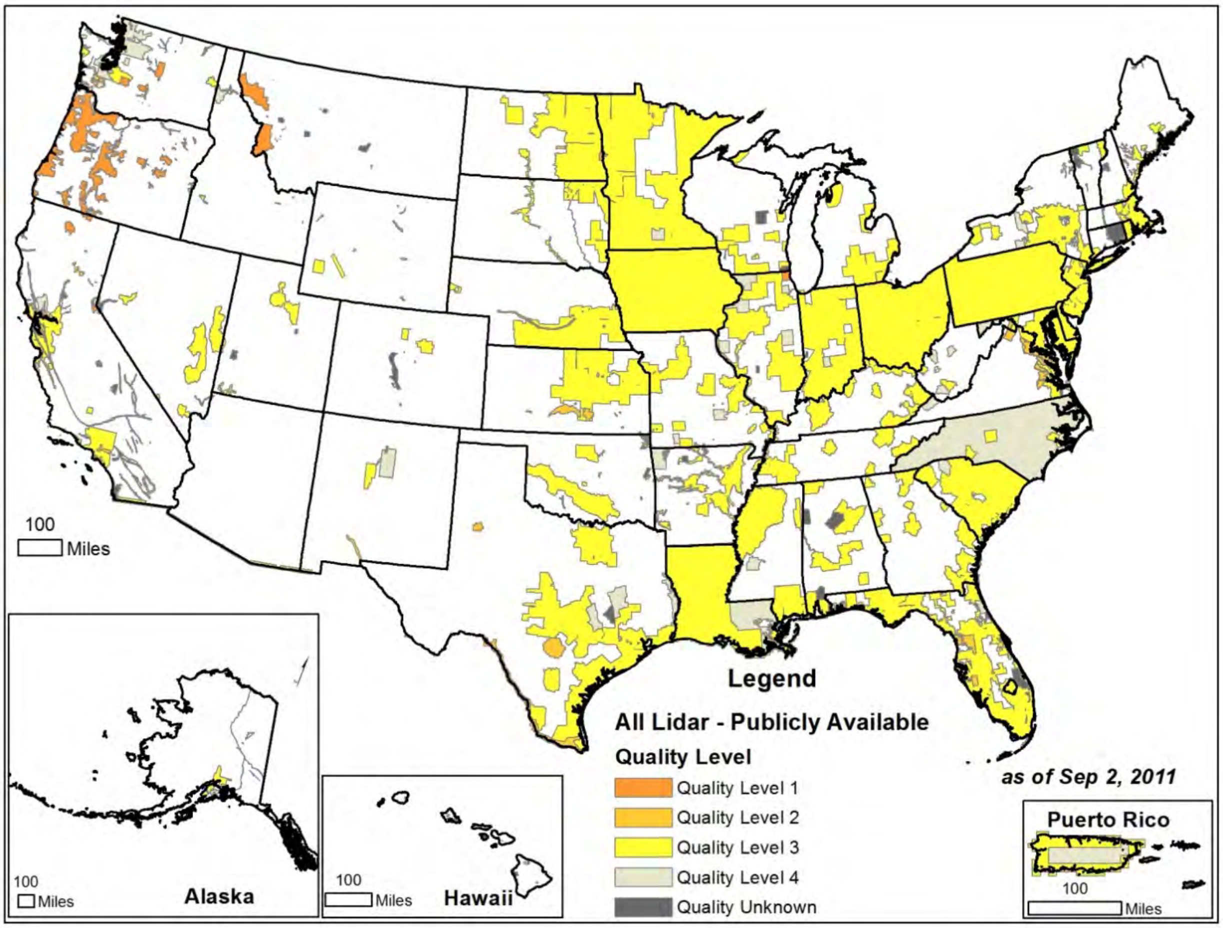


Figure 4.19. Enhanced elevation data inventory, including projects in progress and funded projects.

LiDAR technology emerged in the mid 1990's but its commercial availability was insignificant until about 2001. Figure 4.20 graphs the increase in the LiDAR data inventory, by cumulative percent (along the y-axis) from 2001 to the present (along the x-axis). Ninety plus percent is unrestricted (for public release). The LiDAR inventory is increasing at about 4 percent per year, but increases may not continue at this rate and some states (because of local funding) will have their LiDAR data updated before other states get their first coverage of LiDAR data.

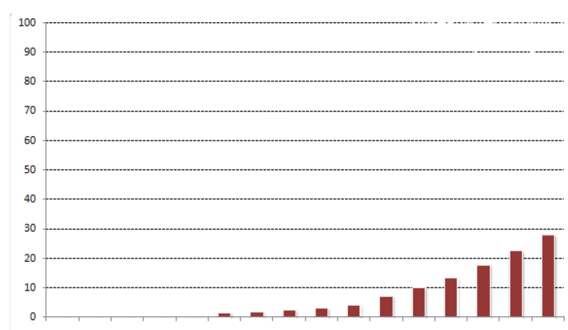


Figure 4.20. Annual increase in the LiDAR data inventory since 2001. The U.S. is currently adding 4% per year.

Data Dictionary for the Elevation Inventory

The information collected from each source was documented in a shapefile providing an approximate outline of the data's spatial extent and key attributes regarding data quality. Dewberry added the existing elevation data inventory to the master geodatabase. The data dictionary for the Data Inventory in the master geodatabase is at Table 4.4.

Table 4.4. Data Dictionary for the Data Inventory Geodatabase

Field Name	Description	Field Definition
FID	System defined unique ID	ObjectID
Index_NEEA	User defined ID	Double
ProjectNam	Project name	Text, 254
Validator	Validator	Text, 50
DataTypeSo	Source data type	Text, 20
Year_Colle	Year collected	Short Integer
LiDAR_PtCl	LiDAR point cloud type	Text, 20
DEM	DEM post spacing	Text, 15
Breaklines	Are breaklines included? (Yes/No)	Text, 10
Contours	Contour equivalent	Text, 15
Horiz_Res	Horizontal resolution	Text, 25
Vert_RMSE	Vertical RMSE	Text, 10
Restrict	Data distribution restrictions	Text, 15
Status_Pro	Project status	Text, 15
QA_3rdPrty	Was 3rd party QA performed? (Yes/No)	Text, 10
POC_Link2d	Point of contact and/or link to data	Text, 254
Notes	Notes	Text, 254
STATE	State name	Text, 2
Area_sqmi	Area in square miles	Double
Vertical	Vertical accuracy	Double
Horizontal	Horizontal accuracy	Double
QL	Equivalent Quality Level	Text, 50
QLComments	QL comments	Text, 50

5. Data Aggregation and Analysis

All data were aggregated and analyzed by 1-degree cells, i.e., 1-degree latitude by 1-degree longitude (nearly 4,000 square miles per cell in the 48 conterminous states, smaller in Alaska). As previously shown in Figures 4.17 and 4.18, 1-degree grids were developed for the 48 conterminous states, and for Alaska, in order to provide a uniform spatial structure within which to aggregate costs and benefits over large areas. Rectangular 1-degree cells are the minimum size for most efficient data acquisition.

5.1 Business Use Requirements and Benefits

Appendix E provides Dewberry's analysis of each Business Use, to include each Functional Activity supporting that Business Use and the Quality Level and update frequencies necessary to satisfy mission-critical requirements for each Functional Activity. Appendix E also summarizes the dollar benefits;

operational benefits internal to the organization; customer service benefits external to the organization; as well as public/social benefits, environmental benefits, and strategic/political benefits for each Functional Activity.

Table E.28 in Appendix E summarizes the conservatively-estimated dollar benefits for each Business Use (totaling $1.180B/year) and explains the potential increased benefits ($12.981B/year) from emerging technologies and other factors that caused dollar benefits for all Business Uses to be understated. These conservative and potential benefits would accrue only if all Functional Activities received the elevation data of the Quality Levels and update frequencies required. Although only the conservative benefits were used in the Benefit Cost Analyses (BCAs) below, the total benefits in the BCAs are less than $1.180B/year because the BCAs were generated from the master geodatabase which did not include the county, regional, city/town and tribal governments documented in Appendix E. These organizations did not have a sufficiently large sample to support benefit extrapolations to the national level.

5.2 Estimation of Costs

It is well known that costs for aerial data acquisition are higher when acquiring imagery, LiDAR or IFSAR of small and/or irregularly shaped areas. In developing the most cost-effective solutions for a nationwide program, only large, rectangular 1-degree cells were considered, requiring the same Quality Level data for each entire cell. USGS obtained average cost estimates from its GPSC2 (Geospatial Products and Services Contract) prime contractors for different size areas (500-1,000 mi^2, 1,000-5,000 mi^2, and >5,000 mi^2) per USGS *LiDAR Guidelines and Base Specifications*, v13 (see Appendix I). Dewberry determined that costs are minimized when rectangular blocks of 5,000 square miles or larger are mapped. Dewberry also assumed the v13 specifications, which currently support QL3 requirements, would be upgraded for more-demanding QL1 and QL2 requirements.

Table 5.1. Average Costs/Mi^2 of LiDAR when Assuming Deliverables Satisfy USGS LiDAR v13 Specifications of Better

Per USGS LiDAR v13 Specifications	$/$mi^2$ for 500-1000 mi^2	$/$mi^2$ for 1000-5000 mi^2	$/$mi^2$ for >5000 mi^2
QL1 LiDAR per upgraded v13 specs	$602.50	$497.00	$453.25
QL2 LiDAR per upgraded v13 specs	$374.50	$310.75	$277.00
QL3 LiDAR per current v13 specs	$291.50	$238.00	$209.25

Each GPSC2 contractor undoubtedly used different assumptions regarding mobilization distances to any part of the country and variable terrain conditions nationwide, for example. The most important information from Table 5.1 is that higher Quality Levels of LiDAR cost significantly more and that large rectangular acquisition areas cost significantly less than smaller areas. For new elevation data, Dewberry recommended acquisition of two or more 1-degree cells (which are around 3,500-4,000 square miles each for the 48 conterminous states) to get the best price per square mile.

The average costs for LiDAR in Table 5.1 pertain to the 48 conterminous states only; for Alaska, Hawaii and U.S. territories, mobilization/demobilization costs will be higher. Dewberry provided its own cost estimates for QL4 DEMs from existing imagery and QL5 DEMs from IFSAR. These estimates, in 2011 dollars, are in column B in Table 5.2 below. Columns C and D include the 15 percent estimated costs of QA/QC to include the survey of QA/QC checkpoints. Column E assumes 5 percent for USGS to manage the acquisition of data. Final NED processing is not included in the 5 percent fee but is included later in the IT implementation costs in Appendix H. Column F includes the total $/mi^2 used in the Benefit Cost Analyses. Dewberry provided cost estimates for Quality Level 5 IFSAR in Alaska ($94.50/mi^2) and reduced costs for Quality Level 5 IFSAR in the other 49 states ($80/mi^2) where acquisition costs are estimated to be about 18 percent lower. Future costs are also dependent on the changing price of aviation fuel and the Consumer Price Index (CPI).

Table 5.2. Estimation of Costs per Square Mile for the Five Quality Levels

A	B	C	D	E	F
Quality Level	**$/mi^2**	**QA/QC**	**Subtotal**	**Admin.**	**Total $/mi^2**
QL1 LiDAR (48 states)	$453.25	$67.99	$521.24	$26.06	$547.30
QL2 LiDAR (48 states)	$277.00	$41.55	$318.55	$15.93	$334.48
QL3 LiDAR (48 states)	$209.25	$31.39	$240.64	$12.03	$252.67
QL4 1-m Image DEM (48 states)	$134.00	$20.10	$154.10	$7.71	$161.81
QL5 IFSAR (Alaska)	$90.00	Included	$90.00	$4.50	$94.50
QL5 IFSAR (49 states)					$80.00

Outside the 48 conterminous states, Dewberry assumes that the costs for LiDAR on distant islands will be higher than shown in Table 5.2, but actual costs are unknown without a rigorous search for airplanes with camera ports (preferably already located on these islands) and without detailed flight planning. LiDAR acquisition costs per square mile for Puerto Rico and the U.S. Virgin Islands will be moderately higher; costs for Hawaii will be much higher, perhaps doubled; and costs for Guam, American Samoa and the Northern Marianas Islands will be much higher and potentially unaffordable.

Estimated total costs (FY 2011 dollars) by Quality Level for the 50 states are as follows:

1. QL1 LiDAR: $1.646B for 48 states; $7.0M for Hawaii; not feasible for major portions of Alaska.
2. QL2 LiDAR: $1.006B for 48 states; $4.3M for Hawaii; not feasible for major portions of Alaska.
3. QL3 LiDAR: $760M for 48 states; $3.2M for Hawaii; not feasible for major portions of Alaska.
4. QL4 Image DEMs: $487.8M for 49 states if and where stereo imagery is already available; N/A for Alaska where stereo airborne imagery is not available.
5. QL5 IFSAR: $241M for new data of 49 states; $53M for new data of the remaining 85% of Alaska.

5.3 Estimation of Benefits

Recognizing that benefits are unrealized if users do not receive the Quality Level and update frequency required, Dewberry developed a procedure for degrading annual dollar benefits with reduced *value multipliers* explained below. In preparation for the Benefit Cost Analyses, the following steps were taken to estimate benefits:

1. Determine the benefits per area unit (sq. mile) for each Functional Activity. This was calculated by dividing the total benefits for each Functional Activity by the geographic area representing the area within which that data are needed.
2. As shown at Figure 5.1, intersect the Functional Activity dataset with the 1-degree grid, resulting in a dataset that divides the Functional Activity data requirement polygons at each grid cell. This

was accomplished by exporting each Functional Activity, intersecting it with the tile grid, and merging all of the Functional Activities back into the geodatabase.

Figure 5.1. Accumulation of Dollar Benefits per Cell for Dozens of Functional Activity Polygons

3. As shown at Figure 5.2, for each new Functional Activity polygon, apply the benefits that will be realized for the total area of that Functional Activity to the new subset area. This subset area is the smaller area created by the intersection of the Functional Activity polygon with the tile grid. This was calculated by multiplying the benefits per area for each Functional Activity by the size of the subset area.

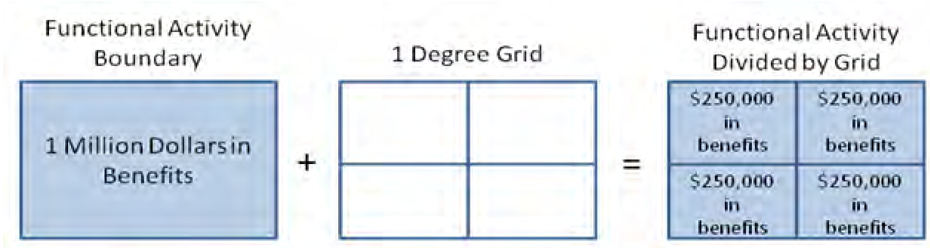


Figure 5.2. Division of Functional Activity Benefits per 1-Degree Grid Cell

An exception was made in the case of Precision Agriculture where benefits accrued only to agricultural lands. Rather than applying benefits equally, USGS provided statistics on the percent of agricultural lands on each 7.5-minute topographic quad map; there are 64 such 7.5-minute quad maps per 1-degree cell. Each of the 64 sub-cells within each 1-degree cell was given a precision agriculture benefit multiplier based on whether agricultural lands comprised 0-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80%, 80-90%, or 90-100%.

4. For each option to be analyzed (options determined for each unique combination of five Quality Levels of data and five update frequencies for the data, totaling 25 options), determine the benefits that would be realized by each Functional Activity.

Each Functional Activity includes benefits that will be realized if a particular Quality Level of data is available with a given update frequency. If a Quality Level and update frequency are provided that are greater than or equal to these requirements, it is assumed that 100 percent of the benefits will be realized for that Functional Activity. However, if a lesser Quality Level or update frequency is provided than the requirements, a reduced percentage of the benefits will be realized, as explained below.

The following method was used to determine the benefits that would be realized for each Functional Activity for multiple options. These options include implementing each of the five Quality Levels at each of the five different update frequencies, resulting in 25 unique options. For each option, a determination is made as to whether it meets the needs of each Functional Activity. If it does, 100 percent of the benefits will be realized. If not, a percentage of the benefits was applied as follows:

- If the update frequency for the option is poorer than the needed update frequency for the Functional Activity, the resulting benefits will be calculated by multiplying the benefits by a *value multiplier* (fraction) specified for each reduction of update frequency as shown in Table 5.3.

Table 5.3. Reduced Benefits for Options when Needed Update Frequency is Not Met

Needed Update Frequency	Option Update Frequency				
	Annually	**2-3 years**	**4-5 years**	**6-10 years**	**>10 years**
Annually	100%	50%	25%	12.5%	6.25%
2-3 years	100%	100%	50%	25%	12.5%
4-5 years	100%	100%	100%	50%	25%
6-10 years	100%	100%	100%	100%	50%
>10 years	100%	100%	100%	100%	100%

- If the update frequency is "event driven," the value multiplier is 50 percent since event driven requirements pertain to the need for elevation data both before and after an event in order to determine the changes caused by the event. A national program could provide the pre-event data, but post-event data would still be required.
- If the Quality Level for the option is greater than the needed Quality Level, the benefits will be multiplied by a fraction specified for each reduction of Quality Level as shown in Table 5.4.

Table 5.4. Reduced Benefits for Options when Needed Quality Level is Not Met

Needed Quality Level	Option Quality Level				
	QL1	**QL2**	**QL3**	**QL4**	**QL5**
QL1	100%	50%	25%	12.5%	6.25%
QL2	100%	100%	50%	25%	12.5%
QL3	100%	100%	100%	50%	25%
QL4	100%	100%	100%	100%	50%
QL5	100%	100%	100%	100%	100%

For example, if a Functional Activity has benefits of $1,000,000 and needed Quality Level 1 data, an option with Quality Level 3 data would result in benefits of $250,000 (25% of $1,000,000).

5.4 Benefit Cost Analyses

Two widely used methods for performing Benefit Cost Analyses are: (1) Net Benefits (NB) where costs are subtracted from the benefits (NB = benefits minus costs); and (2) Benefit/Cost Ratio (B/C Ratio) where the benefits are divided by the costs (B/C Ratio = benefits/costs). Both methods were used for Dewberry's Benefit Cost Analyses. The following steps were taken for the Benefit Cost Analyses:

1. For each 1-degree cell on the grid and each of the 25 options, Dewberry computed the total benefits for all of the intersecting Functional Activity subset areas.

2. For each cell on the grid and each Quality Level, using cost estimates from Table 5.1, Dewberry calculated the costs of data acquisition based on the area of each grid cell. For the update frequency options, the data acquisition costs were then divided by the average number of years per option as shown here.

Update Frequency	Average Years
Annually	1
2-3 years	2.5
4-5 years	4.5
6-10 years	8
>10 years	15

3. For each grid cell and each of the 25 options, Dewberry calculated the Benefit/Cost Ratio (total benefits divided by total costs) and Net Benefits (total benefits minus total costs).
4. For each grid cell, Dewberry calculated the following:
    a. Best Quality Level by Net Benefits
    b. Best update frequency by Net Benefits
    c. Best Quality Level by Benefit/Cost Ratio
    d. Best update frequency by Benefit/Cost Ratio
5. Benefit Cost Analyses were performed separately for federal, state and nongovernmental entities and then for all entities combined. Note that city/town, regional, and tribal governments were not included in the Benefit Cost Analyses; in most cases, no spatial data were provided.
6. For each of the 25 options, Dewberry calculated the Benefit/Cost Ratio and Net Benefits as if each were a national program.
7. Because the Functional Activities for which dollar benefits could not be estimated were not included in the aforementioned Benefit Cost Analyses, the following steps were taken to determine if additional considerations needed to be taken into account:
    a. Dewberry mapped all Functional Activity elevation data requirements most-requested by Quality Level and update frequency for each 1-degree cell for federal, state, and nongovernmental entities and for all entities combined (Figures F.1-F.8. in Appendix F).
    b. Rather than count each Quality Level polygon that intersected each 1-degree cell, Dewberry accumulated the square miles of data required by Quality Level and update frequency for each 1-degree cell and allocated the benefits and costs proportionally.

5.5 Benefit Cost Analysis Results

Appendix F includes details of Dewberry's Benefit Cost Analyses subsequently used to develop program implementation scenarios explained in Section 8 of this report. The Benefit Cost Analyses described in this section were based solely on Functional Activities that were able to estimate dollar benefits.

As documented in Appendix F and summarized below, Figures 5.3 through 5.10 map the Quality Levels and update frequencies that yield the highest net benefits for federal government agencies only, for states only, for nongovernmental organizations only, and for all governmental and nongovernmental organizations combined.

Federal Agencies: To achieve the highest net benefits for federal agencies only, Dewberry determined the optimal Quality Level for each cell and island (each Hawaiian Island and U.S. territorial island), as mapped at Figure 5.3. Dewberry also determined the optimal update frequency for each cell and island, as mapped at Figure 5.4. Although optimized for federal requirements, benefits would accrue also to states and nongovernmental organizations.

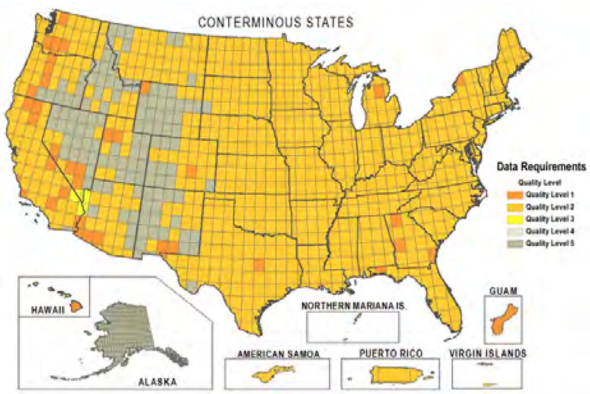


Figure 5.3. Quality Levels to achieve the highest net benefits for federal Functional Activities only.

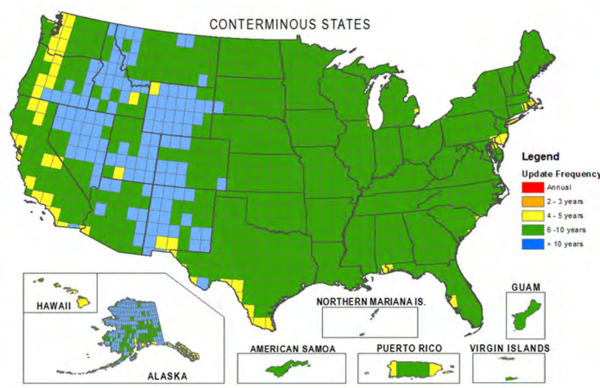


Figure 5.4. Update frequencies to achieve the highest net benefits for federal Functional Activities only.

The major federal CBA statistics are as follows:

Total Costs: $124M/year	**Total Benefits: $252M/year**
Benefit/Cost Ratio: 2.031	**Net Benefits: $128M/year**

State Governments: To achieve the highest net benefits for state governments only, Dewberry determined the optimal Quality Level for each cell and island, as mapped at Figure 5.5. Dewberry also determined the optimal update frequency for each cell and island, as mapped at Figure 5.6.

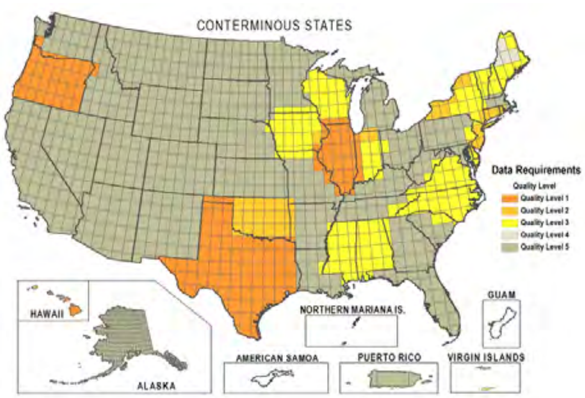


Figure 5.5. Quality Levels to achieve the highest net benefits for state Functional Activities only.

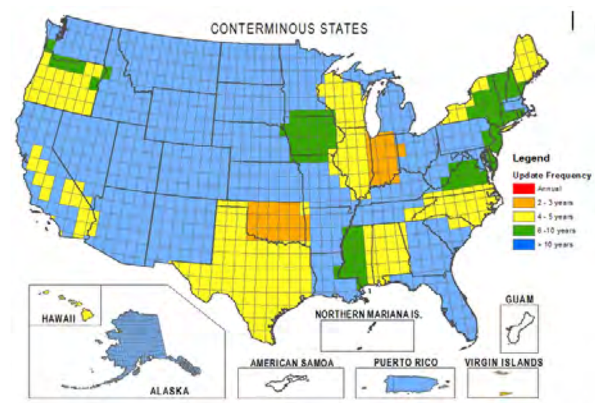


Figure 5.6. Update frequencies to achieve the highest net benefits for state Functional Activities only.

The major state CBA statistics are as follows:

Total Costs: $105M/year	**Total Benefits: $506M/year**
Benefit/Cost Ratio: 4.82	**Net Benefits: $401M/year**

Nongovernmental Users: To achieve the highest net benefits for nongovernmental users, Dewberry determined the optimal Quality Level for each cell and island, as mapped at Figure 5.7. Dewberry also determined the optimal update frequency for each cell and island, as mapped at Figure 5.8.

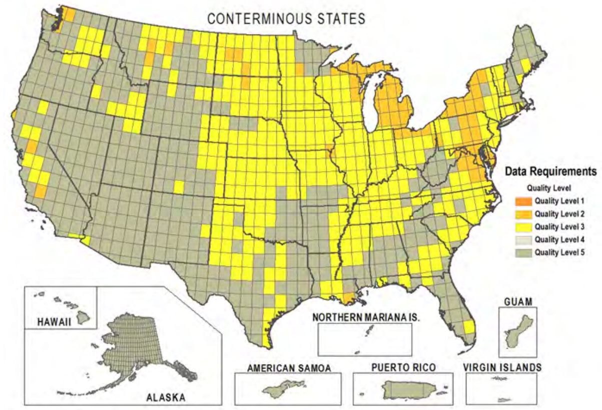


Figure 5.7. Quality Levels to achieve the highest net benefits for nongovernmental Functional Activities only.

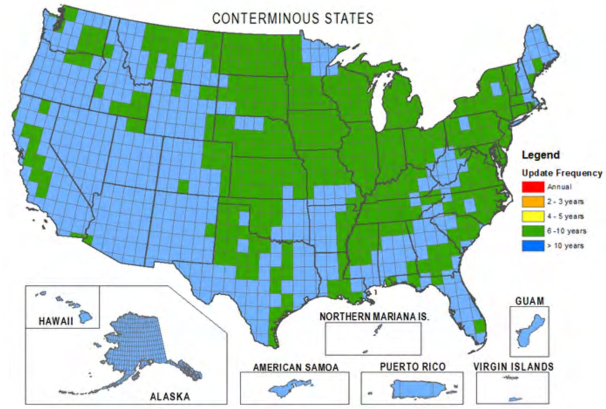


Figure 5.8. Update frequencies to achieve the highest net benefits for nongovernmental Functional Activities only.

The major nongovernmental CBA statistics are as follows:

Total Costs: $60M/year	**Total Benefits: $133M/year**
Benefit/Cost Ratio: 2.206	**Net Benefits: $73M/year**

Combined Federal/State/Nongovernmental: To achieve the highest net benefits for combined federal and state governments plus nongovernmental users (not-for-profit and private companies), Dewberry determined the optimal Quality Level for each cell and island, as mapped at Figure 5.9. Dewberry also determined the optimal update frequency for each cell and island, as mapped at Figure 5.10.

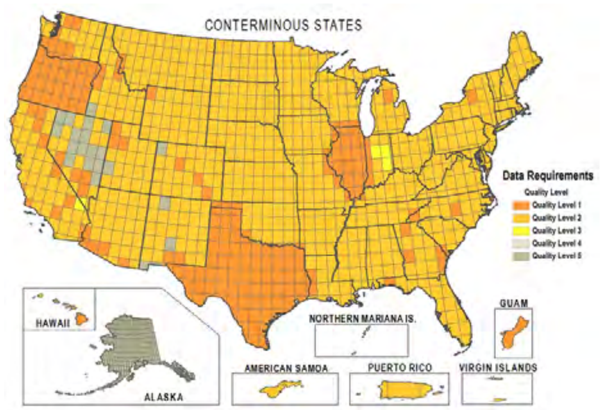


Figure 5.9. Quality Levels to achieve the highest net benefits for federal/state/nongovernmental Functional Activities combined.

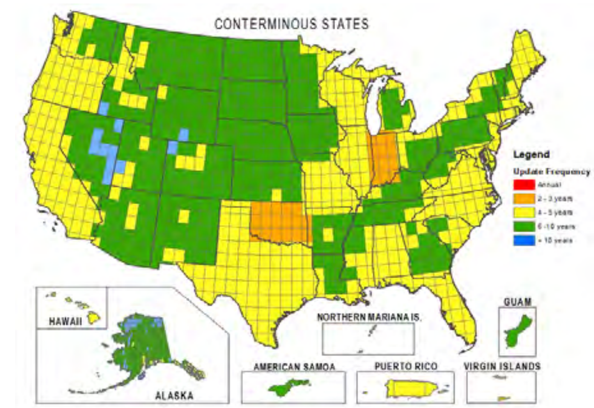


Figure 5.10. Update frequencies to achieve the highest net benefits for federal/state/nongovernmental Functional Activities combined.

The major federal/state/nongovernmental combined CBA statistics are as follows:

Total Costs: $213M/year	**Total Benefits: $1.008B/year**
Benefit/Cost Ratio: 4.728	**Net Benefits: $795M/year**

As shown at Figures 5.9 and 5.10 above, QL2 LiDAR nationwide with update frequency of 4-5 years or 6-10 years provides the highest Net Benefits; but Federal update frequencies are predominantly 6-10 years.

Dewberry also used the power of the geodatabase to evaluate all 25 options (five Quality Levels and five update frequencies) for uniform elevation data (uniform Quality Level and uniform update frequency) for 48 conterminous states, excluding Alaska, Hawaii and U.S. territories. Table 5.5, extracted from Appendix F (Table F.5), tabulates all 25 options and their annual total costs, annual total benefits, annual net benefits and B/C Ratios for each of the 25 options. Net benefits shown with red numbers in parentheses indicate negative net benefits, i.e., the annual total costs exceed the annual total benefits.

In Table 5.5, all dollar values are rounded to the nearest million dollars so as to not infer a higher precision in the calculations of these costs and benefits than warranted. Table F.5 in Appendix F retains the unrounded values as computed.

Total Benefits are accrued from all federal, state and nongovernmental Functional Activities combined. Option 9 (LiDAR QL2, 6-10 year update frequency) provides the best B/C Ratio (5.356) with Net Benefits of $548 million/year.

Table 5.5. Comparison of Benefit/Cost Ratios and Net Benefits for all 25 Quality Level and Update Frequency Options

Option	Quality Level	Update Frequency	Annual Total Costs	Annual Total Benefits	Benefit/Cost Ratio	Net Benefits (Benefits - Costs)
1	1	Annual	$1,646M	$1,111M	0.674	($536M)
2	1	2-3 years	$659M	$1,110M	1.685	$451M
3	1	4-5 years	$366M	$1,066M	2.914	$700M
4	1	6-10 years	$206M	$800M	3.887	$594M
5	1	>10 years	$110M	$403M	3.671	$293M
6	2	Annual	$1,006M	$923M	0.917	($84M)
7	2	2-3 years	$402M	$922M	2.291	$520M
8	2	4-5 years	$224M	$888M	3.970	$664M
9	2	6-10 years	$126M	$674M	5.356	$548M
10	2	>10 years	$67M	$339M	5.049	$272M
11	3	Annual	$760M	$697M	0.917	($63M)
12	3	2-3 years	$304M	$696M	2.291	$392M
13	3	4-5 years	$169M	$673M	3.983	$504M
14	3	6-10 years	$95M	$501M	5.278	$406M
15	3	>10 years	$51M	$252M	4.970	$201M
16	4	Annual	$487M	$361M	0.741	($126M)
17	4	2-3 years	$195M	$360M	1.851	$166M
18	4	4-5 years	$108M	$346M	3.198	$238M
19	4	6-10 years	$61M	$256M	4.204	$195M
20	4	>10 years	$32M	$129M	3.962	$96M
21	5	Annual	$241M	$190M	0.788	($51M)
22	5	2-3 years	$96M	$190M	1.970	$93M
23	5	4-5 years	$53M	$180M	3.365	$126M
24	5	6-10 years	$30M	$131M	4.369	$101M
25	5	>10 years	$16M	$66M	4.118	$50M

The Benefit Cost Analyses demonstrates the synergy achieved if sectors work together to meet their needs. Table 5.6 shows that if the federal government, state governments, and nongovernmental organizations work as independent groups, their subtotal aggregate annual costs would be higher ($289M), their aggregate benefits would be lower ($891M), and the annual net benefits ($602M) would be lower (yellow), than if the groups work in combination to optimize the overall benefit-cost model (green). The Combined Highest Net Benefits option will subsequently be analyzed as Scenario 4 later in this report.

Table 5.6. Synergies obtained from optimal combined solutions compared with organizations acting alone.

User Group	Annual Costs	Annual Benefits	Annual Net Benefits	B/C Ratio
Federal	$124,048,646	$251,971,709	$127,923,063	2.031
State	$104,932,564	$505,700,537	$400,767,973	4.820
Nongovernmental	$60,446,480	$133,374,539	$72,928,059	2.206
Subtotal	$289,427,690	$891,046,785	$601,619,095	3.079
Combined	$213,205,963	$1,007,990,332	$794,784,369	4.728

If selected, the combined solution would have the variable Quality Levels mapped in Figure 5.11 and the variable update frequencies mapped in Figure 5.12. This combined solution is Scenario 4 in Section 8.7 of this report where national program implementation scenarios are evaluated.

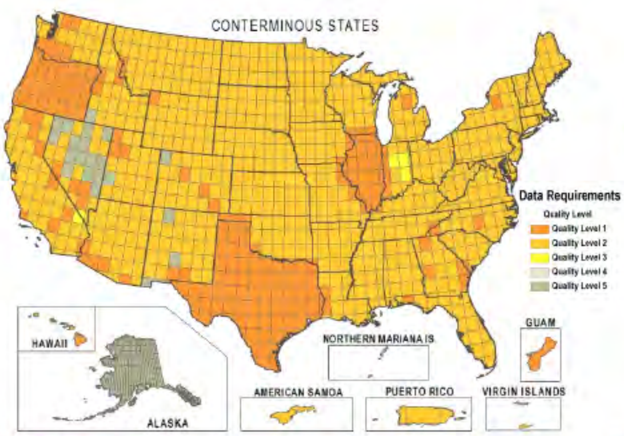


Figure 5.11. Quality Levels to obtain highest net benefits for combined federal/state/nongovernmental users

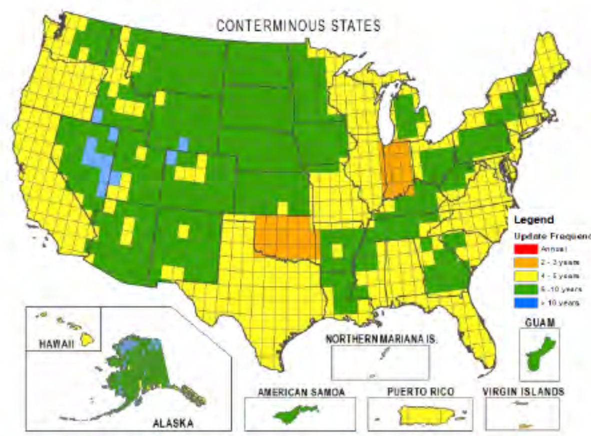


Figure 5.12. Update frequencies to obtain highest net benefits for combined federal/state/nongovernmental users

General Conclusions from Benefit Cost Analyses

When nongovernmental organizations were analyzed as an independent group, QL5 IFSAR was identified as the optimum Quality Level for many 1-degree cells (see Figure 5.7) primarily because of the Wind Farm Siting and Design Functional Activity described in Appendix D. However, because of its low costs, QL5 IFSAR became the default solution in the benefit/cost model whenever benefits from LiDAR were less than the costs of LiDAR. This occurred even when few if any Functional Activities specified IFSAR as required. This occurred for about 13 percent of the 947 1-degree cells when federal organizations were analyzed as an independent group (see Figure 5.3), and for many of the states when states were analyzed as an independent group (see Figure 5.5), but only for about 2 percent of the cells when all organizations were analyzed together (see Figure 5.9).

In Appendix F, Dewberry developed maps showing the most-requested Quality Levels and update frequencies for federal agencies only, for states only, for nongovernmental organizations only, and for all combined. The combined most-requested Quality Levels and update frequencies are mapped at Figures 5.13 and 5.14. With variable Quality Levels, the most-requested update frequency is 6-10 years.

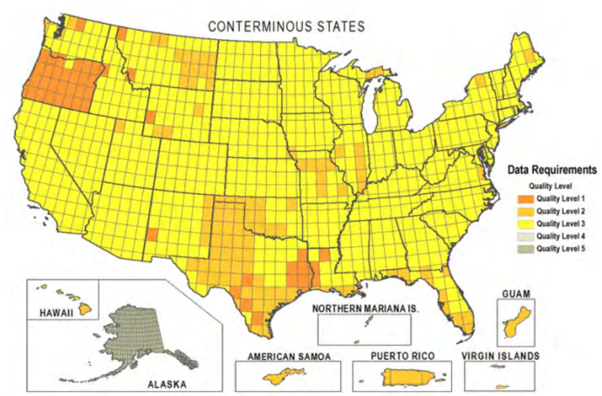


Figure 5.13. Nationwide, QL3 LiDAR is the most-requested Quality Level; others shown are QL1 and QL2 LiDAR with QL5 IFSAR in Alaska.

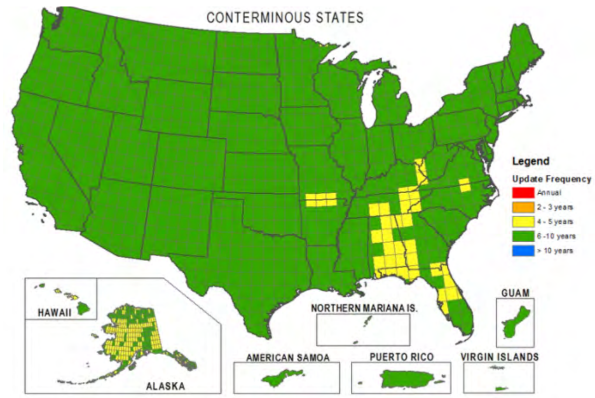


Figure 5.14. Nationwide, 6-10 years (shown in green) is the most-requested update frequency; the remainder are 4-5 year updates (shown in yellow).

When considering federal requirements only, QL3 LiDAR, updated every 6-10 years, is the most-requested. When considering federal dollar benefits only, QL2 LiDAR, updated every 6-10 years, provides the highest net benefits for most of the country (Figures 5.3-5.4).

When considering state requirements only, different states require LiDAR at QL1, QL2 and QL3, with update frequencies of 2-3 years, 4-5 years and 6-10 years. When considering state dollar benefits only, four states (Hawaii, Oregon, Texas and Illinois) receive the highest net benefits from QL1 LiDAR, three states (Oklahoma, Massachusetts and Rhode Island) receive the highest net benefits from QL2 LiDAR, ten states receive the highest net benefits from QL3 LiDAR (with some QL2 LiDAR), but 33 states receive the highest net benefits from QL5 IFSAR, even though they may have specified no requirements for IFSAR, largely because they were unable to estimate benefits that exceeded the costs of LiDAR (Figure 5.5). These variances are based totally on input received from state participants in the NEEA process.

When considering nongovernmental requirements only (including not-for-profit and private companies), QL3 LiDAR, updated every 6-10 years, is the most-requested. When considering nongovernmental dollar benefits only, QL2 LiDAR, updated every 6-10 years, provides the highest net benefits for about half of the country (largely where there are agricultural lands that would benefit from LiDAR used for precision agriculture), whereas about half of the country would default to QL5 IFSAR, updated >10 years because there are not enough benefits to exceed the cost of LiDAR (Figures 5.7-5.8).

When considering combined requirements (from federal, state and nongovernmental users combined), QL3 LiDAR, updated every 6-10 years, is the most requested. When considering combined net dollar benefits, variable Quality Levels and update frequencies are justified for individual 1-degree cells, as shown in Figures 5.11 and 5.12 above. This became Scenario 4 when assessing eight national program implementation scenarios in section 8.7 of this report.

Table 5.5 shows that, for all Quality Levels, an update frequency of 4-5 years provides higher net dollar benefits, but an update frequency of 6-10 years provides higher B/C Ratios.

Section 8 of this report will consider these Benefit Cost Analyses and BCA results from Section 5 in development of alternative National Program Implementation Scenarios.

6. Technology Trends and Risk Considerations

At Appendix G, Dewberry evaluated the opportunities, challenges and risks to a nationwide enhanced elevation program from a variety of factors including the following:

1. Changes to topographic LiDAR technologies.
2. Changes to bathymetric and topobathymetric LiDAR technologies.
3. Evolving airborne and satellite IFSAR technologies, including the changing role of satellite Differential Interferometric Synthetic Aperture Radar (DINSAR) for repeat-pass interferometry.
4. Changes to enabling technologies, including inertial measurement units (IMUs), airborne GPS, and Continuously Operating Reference Stations (CORS).
5. Changes to the geoid model resulting from NGS' Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project.
6. NGS changes to the horizontal and vertical datums in the 2020's from which all geospatial coordinates are referenced.
7. Capacity of commercial LiDAR vendors to collect and process data in a timely and cost-effective manner.
8. Evolving LiDAR standards and guidelines.
9. Evolving LiDAR QA/QC procedures.
10. Uncertainties in ability of USGS to deliver standard elevation products, elevation derivatives, and LiDAR point cloud data.
11. Uncertainties in intents of Google, Amazon, Microsoft, Esri and others to serve standard elevation products, elevation derivatives, and LiDAR point cloud data to the public as elevation data are provided by federal agencies and/or states.
12. Uncertainties in elevation data archiving and storage requirements, including funding.
13. Uncertainties in the role of "cloud computing."
14. Potential risks to the stable funding for elevation data lifecycle acquisition, management and maintenance.
15. Changing user requirements and/or benefits.

Dewberry's conclusions regarding these risk factors are summarized below.

6.1 Topographic LiDAR Technology

- Technology trends show continued evolutionary improvements in topographic LiDAR system technologies, but not revolutionary improvements that would justify delays in implementing a national elevation program over a 4-7 year timeframe.
- All Business Uses with mission-critical requirements for LiDAR data can be satisfied with today's topographic LiDAR technologies so that the major benefits could be realized without delay as funds become available for nationwide elevation program based on LiDAR.

- Evolving topographic LiDAR technologies will improve LiDAR acquisitions in the next decade but the expectation of improved capabilities should not delay implementation of new enhanced elevation programs.

6.2 IFSAR/InSAR Technology

- IFSAR data (satellite or airborne) lack the resolution and accuracy required to satisfy most Business Use requirements for the NEEA, and hence is not considered a viable solution for obtaining QL1 – QL4 data.
- In Alaska, where clouds and fog severely limit the acquisition of LiDAR and optical imagery, airborne IFSAR is superior due to its ability to map through clouds and fog; it is also superior in Alaska because it maps large, remote areas at relatively low costs.
- Airborne IFSAR is normally ill-suited for updating elevations previously derived from LiDAR data because it has poorer accuracy, poorer resolution and (normally) poorer currency. The one scenario where IFSAR could update LiDAR data is when new IFSAR data are more current than old LiDAR data and could depict topographic changes, such as shown in Figures G.12 through G.19 in Appendix G.
- Satellite DInSAR offers potential for mapping changes in water surface elevations – something that airborne IFSAR cannot do well.

6.3 Bathymetric LiDAR Technology

- As with topographic LiDAR, technology trends show continued evolutionary improvements in topobathymetric LiDAR system technologies.
- For coastal mapping starting in 2012, the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) is expected to employ multiple Coastal Zone Mapping and Imaging LiDAR (CZMIL) systems to start collecting topobathymetric data of U.S. coastlines for the National Coastal Mapping Program.
- For nautical charting, NOAA's Office of Coast Survey will be better able to perform its mission with emerging bathymetric LiDAR systems that perform better in turbid and/or shallow waters.
- For riverine mapping, many federal and state agencies are eager to see if emerging topobathymetric LiDAR systems will in fact be able to map rivers and streams that are turbid and/or shallow; this is the major need currently unmet by today's topobathymetric technologies.

6.4 Other Considerations for a National Enhanced Elevation Program

- The change to the new vertical (geopotential) reference frame will be a combination of the geoid model developed primarily through the National Geodetic Survey's Gravity for the Redefinition of the American Vertical Datum (GRAV-D) program and the adoption of the geometric reference frame aligned to the International Terrestrial Reference Frame (ITRF). Consequently, all elevations will be a function of geoid refinements and are expected to change.
- Although changing horizontal and vertical datums will impact all geospatial data a decade from now, such datum changes will not hamper an initial implementation of a National Enhanced

Elevation Program, regardless of the elevation data Quality Level selected. When the new geometric reference frame is implemented in the 2020's, new elevation data will be produced to the new datum and existing elevation data can be converted from the current North American Vertical Datum of 1988 (NAVD 88) to the new vertical datum.

- As LiDAR technology continues to mature, changing hardware and software trends will not hamper a consistent implementation of nationwide LiDAR but will provide additional tools for data providers and professional users, and quick/simple 3-D viewing options for non-professional users.
- Future improvements to LiDAR hardware and software could impact the overall Benefit Cost Analysis performed for the NEEA because these improvements are expected to result in lower costs for acquisition and processing of data and new potential benefits; these future improvements would not suggest a delay in implementation because elevation technologies will continue to improve.
- When considering any of the eight program implementation scenarios explained in Section 8, the capacity risk is minimal.
- USGS' *LiDAR Guidelines and Base Specifications* must be finalized for LiDAR QL1, QL2 and/or QL3 data before initiating a consistent implementation of nationwide LiDAR at any of these Quality Levels. Intermap's "Product Handbook and Quick Start Guide" already serves as the consistent Guidelines and Specifications for airborne IFSAR data of the U.S. including DTMs, DSMs and ORIs. Potential revisions to USGS' *LiDAR Guidelines and Base Specifications* should have no significant impact on the overall Benefit Cost Analysis performed for the NEEA unless new requirements are added that increase the pricing per square mile.
- For consistent implementation of nationwide LiDAR, it is imperative that consistent *LiDAR Guidelines and Base Specifications* be used and that independent QA/QC be performed in a consistent manner nationwide. Potential changes to QA/QC procedures will have no significant impact on the overall Benefit Cost Analysis performed for the NEEA unless new QA/QC requirements are added that cannot be satisfied by the 15% added costs assumed for survey of QA/QC checkpoints and independent QA/QC.
- For consistent implementation of nationwide LiDAR, the program would need to operate against a clear set of standards for data collection and derivative product generation.
- For either topographic data or bathymetric data, reliable elevation data must be available from USGS, NOAA, FEMA and/or other organizations and cooperating partners before anybody (e.g., Google, Microsoft, ESRI, OpenTopography Portal, etc.) can serve it to the public for the hundreds of diverse applications highlighted in this report. Any solution for elevation data needs to include adequate resources for lifecycle management and maintenance.
- Conservatively-estimated benefits from federal, state, county, regional, city/town and tribal governments were all significantly understated in the Benefit Cost Analysis. Furthermore, Dewberry determined that it would be premature to count major benefits expected to occur as a result of elevation-based roadway geometry required for Intelligent Transportation System (ITS), IntelliDrive, and/or Advanced Driver Assistance System (ADAS) initiatives that are expected to save lives as well as billions of dollars annually for America's drivers. For these reasons,

Dewberry expects that future changes to benefits in the Benefit Cost Analysis will cause most B/C Ratios and net benefits to increase rather than decrease.

7. Information Technology Infrastructure

A National Enhanced Elevation Program will need to be supported by an information technology (IT) infrastructure that allows elevation data to be properly stored, administered, and served to broad communities of use and the public. This IT infrastructure will serve as the data management backbone for the national program, including necessary hardware, software, networks, and support that provide a repository for elevation data after acquisition.

The assessment provided in Appendix H was derived from discussions with organizations currently managing enhanced elevation data at a national scale in order to provide a general overview of the types of functionality to be expected from this infrastructure and a rough order of magnitude of costs for the hardware and software. This information can be used to further analyze the feasibility of national program alternatives and to guide initial planning of program implementation strategies. Further analyses will need to be performed if a national program is planned and established, to determine the specific requirements for this technology and the most appropriate architecture and implementation strategy. Appendix H introduces the types of capabilities expected of an IT infrastructure, followed by the specific needs for each of these capabilities and technology options and associated costs to meet these needs.

The complete costs for each of the major infrastructure components are summarized in Table 7.1 below.

Table 7.1. Summary Costs for the National Enhanced Elevation Program Infrastructure

Item	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Total
Data Storage	$11.3M to $14.0M	$3.0M to $4.9M	$2.4M to $4.6M	$2.4M to $4.6M	$9.4M to $15.5M	$4.4M to $10.2M	$3.2M to $9.1M	$3.2M to $9.1M	**$39.1M to $71.9M**
Data Processing	$142K to $359K	$18K to $44K	$18K to $44K	$18K to $44K	$18K to $44K	$18K to $44K	$18K to $44K	$18K to $44K	**$320K to $794K**
Data Provisioning	$2.0M to $3.4M	$233K to $792K	$233K to $873K	$233K to $954K	$233K to $1.0M	$717K to $1.9M	$233K to $1.6M	$233K to $1.7M	**$4.1M to $12.3M**
Support Staff	$1.8M to $2.2M	$1.9M to $2.3M	$2.0M to $2.4M	$2.1M to $2.5M	$2.1M to $2.6M	$2.2M to $2.7M	$2.3M to $2.8M	$2.4M to $2.8M	**$16.7M to $20.3M**
Support Technology	$362K	$60K	$60K	$60K	$60K	$230K	$60K	$60K	**$955K**
Subtotal	**$15.6M to $20.4M**	**$5.2M to $8.1M**	**$4.6M to $7.9M**	**$4.7M to $8.1M**	**$11.9M to $19.2M**	**$7.6M to $15.2M**	**$5.7M to $13.5M**	**$5.8M to $13.8M**	**$61.5M to $106.2M**
Cumulative Total	**$15.6M to $20.4M**	**$20.8M to $28.5M**	**$25.5M to $26.4M**	**$30.3M to $44.5M**	**$42.1M to $63.7M**	**$49.8M to $78.9M**	**$55.6M to $92.4M**	**$61.5M to $106.2M**	

The costs included in this table vary based on the options available for each infrastructure component. Based on these summary costs, a minimum of approximately $61.5 million will be needed to implement and maintain the technology infrastructure and data management responsibilities over the initial 8-year lifecycle. A minimum of approximately $15.6 million will be needed to stand up the system, with an average of $6.5 million per year needed over the remaining seven years of an 8-year implementation scenario. As additional requirements are implemented in the program, this cost can increase up to $106 million over an 8-year implementation scenario and even more for a 15-year implementation scenario.

These IT costs are added to the cost of the elevation data to determine total life cycle costs in Section 8, National Program Implementation Scenarios.

The costs in this table are based on many assumptions about the user needs, the data that it will need to support, and estimates of usage of the system. As the national program is implemented, additional planning should be conducted to gain further insight into specific methods that users would use to interact with the elevation data and how the system requirements should be enacted to respond to these needs. This investigation will help narrow the focus on specific functionality and help estimate options and costs for delivering this functionality.

8. National Program Implementation Scenarios

Approximately 28.4 percent of the combined area of the lower 49 states plus Washington D.C. is covered by publically available LiDAR data, ranging from QL1 to QL4;15.2% of Alaska has QL5 IFSAR data. Most existing data are of a lower QL than required by the majority of federal, state and nongovernmental Functional Activities identified in this assessment. Table 8.1 identifies the percent, by quality level, of the lower 49 states (plus D.C.) that is covered by publically available LiDAR data.

Table 8.1. Summary of Public Domain LiDAR Data

LiDAR Data Quality Level (QL)	Square Miles of Data Over the Lower 49 States + D.C.	Percent Coverage of the Area of the Lower 49 States + D.C.
QL1 LiDAR	27,912 mi^2	0.9%
QL2 LiDAR	22,160 mi^2	0.7%
QL3 LiDAR	728,103 mi^2	23.7%
QL4 LiDAR	94,100 mi^2	3.1%
Totals	**872,276** mi^2	**28.4%**

Although not included in this table, some QL4 data are also available from photogrammetry, and small areas of Alaska have QL3 LiDAR data. Other elevation datasets are proprietary and not publically available.

The current or "status quo" state of LiDAR collection is widely considered to be unacceptable. At the current data collection rate it would take 35 years to collect nationwide data. It is also likely that portions of the country would remain unmapped while others would be remapped several times over.

Figure 8.1 maps the location of the various Quality Levels of enhanced elevation data, mostly acquired since 1998. Although it was the first to obtain statewide LiDAR, North Carolina is shown in Figure 8.1 as having QL4 data because the LiDAR vertical accuracy and horizontal resolution are poorer than specified for QL3 LiDAR in Table 1.2.

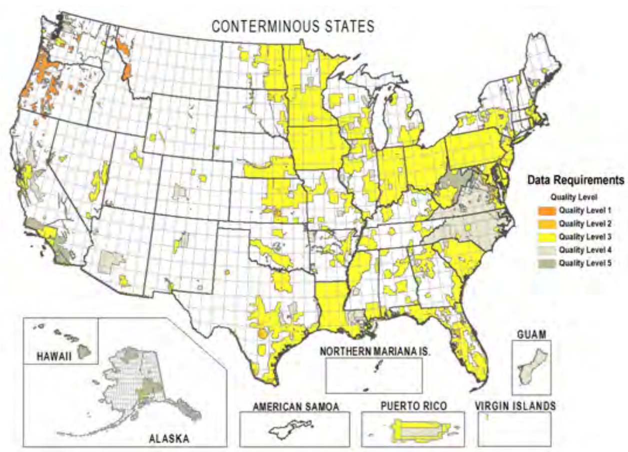


Figure 8.1. Status quo, enhanced elevation data inventory including projects in progress and funded projects.

In recent years, enhanced elevation data have been added to the inventory at an average rate of approximately 4 percent per year; however, this is not the norm because a significant percentage of this increase resulted from American Recovery and Reinvestment Act (ARRA) funding which is not continuing. Even if the status quo were to provide complete coverage in 35 years, that would clearly be inadequate to meet the many federal, state and nongovernmental user requirements for enhanced elevation data at a 6-10 year update frequency.

As alternatives to the status quo, based on all of the Benefit Cost Analyses performed on the data collected for the NEEA, four primary National Program Implementation Scenarios were developed and analyzed by Dewberry. All four scenarios include QL5 IFSAR for Alaska (where LiDAR has technical challenges due to cloud cover and fog, and is more difficult to justify in benefit cost analyses except in populated areas). Whereas the status quo scenario is largely decentralized (characterized by opportunistic data collection partnerships) the following National Program Implementation Scenarios are partially or fully centralized. Each program scenario would include "buy up" options should other organizations find it necessary to acquire higher quality data.

- Scenario 1 – QL3 LiDAR with 25-year acquisition period: the lowest-cost alternative, it would yield consistent QL3 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska over a 25-year acquisition period.
- Scenario 2 – Mixed QL1/2/3 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska with 8-year acquisition period: a medium cost alternative optimized for federal requirements and to provide the best federal net benefits. Many organizations were unable to provide quantified dollar benefits for their Functional Activities. To give due consideration to these requirements, this scenario used the most-requested Quality Level as a weighting factor (in addition to dollar benefits) in computing the optimal QL and frequency update. It is the only scenario to use the most-requested Quality Level as a weighting factor.
- Scenario 3 – QL2 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska with 8-year acquisition period: a medium cost alternative that would yield QL2 LiDAR uniformly over 49 states and U.S. territories.
- Scenario 4 – Mixed QL1/2/3 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska with 8-year acquisition period: the scenario that collectively optimizes the combined benefits of federal/state/nongovernmental requirements, and yields the highest combined net benefits (at the highest cost).

These four primary implementation scenarios are based on acquisition periods of 25 years, 8 years, 8 years, and 8 years, respectively. In addition, four alternative implementation scenarios (1A-4A), corresponding to each of the four primary scenarios, were computed based on acquisition periods of 15 years. The alternative scenarios use the same Quality Levels per 1-degree cell as the primary scenarios. The four primary and four alternative implementation scenarios analyzed in this report are derived from the results of Benefit Cost Analyses described in Appendix F. All eight options would lead to national data coverage, provide a positive return on investment (ROI), and provide flexibility in terms of state and local "buy ups" to increase data quality or modify the data collection schedule.

The following paragraphs define three terms used above in the context of data collection efforts:

- A "decentralized" program describes the opportunistic data collection programs in place today. The status quo is not nationally directed with respect to geographic coverage, quality, schedule or who participates in data collection activities. Projects are characteristically independently planned and completed where and when interests and funding allow, at various levels of contribution, using a variety of contracts and specifications, by some organizations having capabilities to manage a project and others not having these capabilities.
- A "fully centralized" program would involve a single entity (presumably a federal agency) that receives full funding and has the responsibility to implement a national program of agreed-upon data quality and collection frequency. The federal government would consider a full spectrum of

national requirements to implement such a program. A "fully centralized" program would result in the most consistent data and likely the lowest cost data, given the expected regular collection and economies of scale in contract negotiations. The states or other partners would have less influence on all aspects of the program.

- "Partly centralized" is a partnership model where contributors share control of priorities affecting data quality, collection schedules and coverage areas. This would likely involve greater data variation, reduced consistency, and in some cases higher costs per square mile. Such a program could be less efficient but would lower the cost to any one partnership entity. Program priorities would be more focused on meeting partnership needs.

All program scenarios considered for this assessment are at least partly centralized. Dewberry assumes that USGS, because of its OMB Circular A-16 responsibilities, would manage elevation data acquisition, to include Quality Level specifications, scheduling, contracting, QA/QC, and creation of basic derivative products. All data would be centrally archived and disseminated, to include a basic suite of derivative products. Partners could "buy-up" to increase the Quality Level or update frequency of the data collected if they would contribute the additional cost it would take to acquire the data over and above the costs of the programmed data acquisition. Partners and/or users would be free to create and distribute additional derivative products based on their program and/or project requirements.

Scenario Common Advantages

All eight implementation scenarios have common advantages compared with the status quo:

1. A centralized or partly centralized National Enhanced Elevation Program makes the most sense in terms of contracting, continuity, specification alignment, and adherence to uniform acceptance criteria; resulting products are more likely to be consistent and compatible with adjoining elevation datasets, have good metadata, and be acceptable for a national program.
2. Acquisition of data and delivery of products to the USGS *LiDAR Guidelines and Base Specifications*, v13 (see Appendix I), or updates thereto, assures consistent, high-quality elevation data whereas acquisition of data to diverse alternative specifications often results in lower-quality data that may not be accepted for inclusion in a national program for public distribution.
3. A nationwide collection schedule would be developed and published so users know when and where areas are planned to be collected over a known acquisition cycle. If this Quality Level or acquisition schedule does not meet user requirements, they can "buy-up" to meet their needs.
4. Assuming the LiDAR and IFSAR data are systematically acquired in full 1-degree cells, the costs per square mile will be considerably lower than the higher costs typically paid under the status quo for smaller, irregularly-shaped areas at different Quality Levels.
5. The large-scale acquisition program would be managed by elevation data experts who are well versed in LiDAR and IFSAR data specifications, contracting requirements, and QA/QC procedures and requirements.
6. Users would have a 1-stop, reliable source of high-accuracy, high-resolution elevation data rather than researching multiple sources to determine the best available data.

7. Users would be able to more easily discover and obtain enhanced elevation data; they would know what Quality Level specifications, age and acquisition period, and derivative products to expect.
8. Consistent data standards nationwide would facilitate the development of applications software based on known data accuracy and density parameters.
9. Under any of the major scenarios, nationwide coverage of enhanced elevation data that are uniform and/or consistent in terms of data acquisition methodology, Quality Level, age and update frequency, QA/QC, metadata, and derivative products would generally be assured by the end of the first-pass collection cycle.
10. With all major scenarios, nationwide enhanced elevation data is expected to be in the public domain in concert with current distribution practices for the National Elevation Dataset.

Scenario Common Disadvantages / Challenges

All eight implementation scenarios also have common challenges compared with the status quo:

1. All eight scenarios require some level of new and stable funding.
2. For all scenarios, existing IT infrastructure would need to be upgraded to improve reliability and scaled to handle larger volumes of data and new services to users.
3. Centralized programs may cause state and local users to assume this is solely a federal responsibility and thereby reduce their own efforts to promote needed funding partnerships.

Note: In each of the eight scenarios explained below, a small bolded summary box is provided that lists four key statistics for elevation data only, to include annual costs, benefits, net benefits, and Benefit/Cost Ratios, but excluding information technology (IT) infrastructure costs. Each summary box of key statistics for data is then immediately followed by a Table that provides the cumulative lifecycle costs, including IT infrastructure costs, for each of the eight scenarios.

8.1 Scenario 1 – Uniform QL3 LiDAR, 25-year Acquisition Period

As shown in Figure 8.2, under Scenario 1, uniform QL3 LiDAR would be acquired over a 25-year acquisition period for 49 states and U.S. territories and QL5 IFSAR would be acquired for Alaska. [Alaska also has requirements for LiDAR data, but persistent cloud and fog conditions make it technically difficult and expensive to acquire LiDAR in Alaska, though some LiDAR has been acquired of small, priority areas within the state.]

Figure 8.2. Scenario 1, Uniform QL3 LiDAR nationwide except QL5 IFSAR for Alaska; 25-year acquisition period; lowest cost and lowest benefits scenario.

Scenario 1 would result in the following annual data costs and benefits from the LiDAR and IFSAR data, excluding IT costs for data management and dissemination.

Total Annual Data Costs: $32.7M/year	**Total Annual Data Benefits: $148.4M/year**
Data Benefit/Cost Ratio: 4.538	**Net Annual Data Benefits: $115.7M/year**

Table 8.2 accumulates the annual costs and benefits over the 25-year lifecycle of Scenario 1, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.2. Scenario 1 Cumulative Lifecycle Costs and Benefits (in $ millions) over 25-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
LiDAR Data Costs	$31	$61	$92	$122	$153	$183	$214	$244	$275
IFSAR Data Costs	$2	$4	$6	$8	$11	$13	$15	$17	$19
IT Costs	$2	$5	$7	$10	$12	$15	$17	$20	$22
Combined Costs	$35	$70	$105	$140	$176	$211	$246	$281	$316
Combined Benefits	$148	$297	$445	$594	$742	$890	$1,039	$1,187	$1,336
Costs and Benefits	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Year 16**	**Year 17**	**Year 18**
LiDAR Data Costs	$305	$336	$366	$397	$427	$458	$488	$519	$550
IFSAR Data Costs	$21	$23	$25	$28	$30	$32	$34	$36	$38
IT Costs	$25	$27	$30	$32	$34	$37	$39	$42	$44
Combined Costs	$351	$386	$421	$456	$492	$527	$562	$597	$632
Combined Benefits	$1,484	$1,632	$1,781	$1,929	$2,078	$2,226	$2,374	$2,523	$2,671
Costs and Benefits	**Year 19**	**Year 20**	**Year 21**	**Year 22**	**Year 23**	**Year 24**	**Year 25**	**25-Year Total**	
LiDAR Data Costs	$580	$611	$641	$672	$702	$733	$763	**$763M**	
IFSAR Data Costs	$40	$42	$45	$47	$49	$51	$53	**$53M**	
IT Costs	$47	$49	$52	$54	$57	$59	$62	**$62M**	
Combined Costs	$667	$702	$737	$772	$807	$843	$878	**$878M**	
Combined Benefits	$2,820	$2,968	$3,116	$3,265	$3,413	$3,562	$3,710	**$3,710M**	

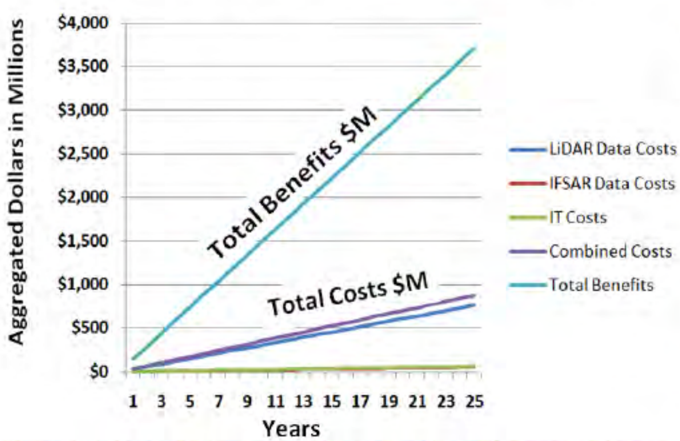


Figure 8.3. Scenario 1 aggregated costs and benefits over a 25-year implementation period when including data and IT costs.

Figure 8.3 graphs the data in Table 8.2 which aggregates lifecycle costs over the 25-year acquisition period. Over 25 years, the total costs (in 2011 dollars) would be $763M for LiDAR, $53M for IFSAR (in Alaska) and $62M for IT costs – totaling $878M in costs over 25 years. The total benefits would be $3.710 billion; and the total net benefits would be $2.832 billion. When including IT costs, the overall Benefit/Cost Ratio is 4.226.

Scenario 1 Advantages

- Lowest annual and lifecycle costs of all scenarios.
- Upon completion, uniform QL3 LiDAR for 49 states and U.S. territories consistently produced to the current USGS *LiDAR Guidelines and Base Specifications*, v13.

Scenario 1 Disadvantages

- Poorest Quality Level and poorest update frequency of all scenarios.
- Fewest *mission-critical* requirements (12.6%) satisfied for Business Uses and Functional Activities.
- Lowest total and net benefits of all scenarios.
- Poorest Benefit/Cost Ratio of all scenarios.

- Nationwide coverage of enhanced elevation data is less likely, even with 25 years to complete coverage, because of the challenge of maintaining agreements and the likelihood that states and priority areas with available funding are likely to acquire data multiple times over a quarter century, while some areas will likely never be covered.

8.2 Alternative Scenario 1A, 15-year Acquisition Period

If Scenario 1 data were acquired using a 15-year acquisition period, instead of 25-years, the following data costs and benefits would apply for a Scenario 1A:

Total Annual Data Costs: $54.5M/year	**Total Annual Data Benefits: $261.1M/year**
Data Benefit/Cost Ratio: 4.791	**Net Annual Data Benefits: $206.6M/year**

Table 8.3 accumulates the annual costs and benefits over the 15-year lifecycle of Scenario 1A, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.3. Scenario 1A Cumulative Lifecycle Costs and Benefits (in $ millions) over 15-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
LiDAR Data Costs	$51	$102	$153	$204	$254	$305	$356	$407
IFSAR Data Costs	$4	$7	$11	$14	$18	$21	$25	$28
IT Costs	$4	$8	$12	$16	$21	$25	$29	$33
Combined Costs	$59	$117	$176	$234	$293	$351	$410	$468
Combined Benefits	$261	$522	$783	$1,044	$1,306	$1,567	$1,828	$2,089
Costs and Benefits	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
LiDAR Data Costs	$458	$509	$560	$611	$661	$712	$763	**$763M**
IFSAR Data Costs	$32	$35	$39	$42	$46	$49	$53	**$53M**
IT Costs	$37	$41	$45	$49	$53	$57	$62	**$62M**
Combined Costs	$527	$585	$644	$702	$761	$819	$878	**$878M**
Combined Benefits	$2,350	$2,611	$2,872	$3,133	$3,394	$3,655	$3,917	**$3,917M**

Scenario 1A Comparison with Scenario 1

Uniform QL3 LiDAR data would be available earlier (15 year cycle), satisfying more *mission-critical* requirements and yielding higher benefits. The average annual lifecycle costs for Scenario 1A ($59M /year) are higher than the average annual lifecycle costs for Scenario 1 ($35M/year), but the average annual lifecycle benefits for Scenario 1A ($261M/year) are also much higher than the average annual lifecycle benefits for Scenario 1 ($148M/year). The lifecycle B/C Ratio changes from 4.226 for Scenario 1 to 4.461 for Scenario 1A.

8.3 Scenario 2 – Mixed QL1/2/3 LiDAR, 8-year Acquisition Period

As shown in Figure 8.4, under Scenario 2, QL2 LiDAR would be acquired for most of the 48 conterminous states with some QL1 LiDAR (burnt orange) and some QL3 LiDAR (yellow) cells plus QL5 IFSAR for Alaska.

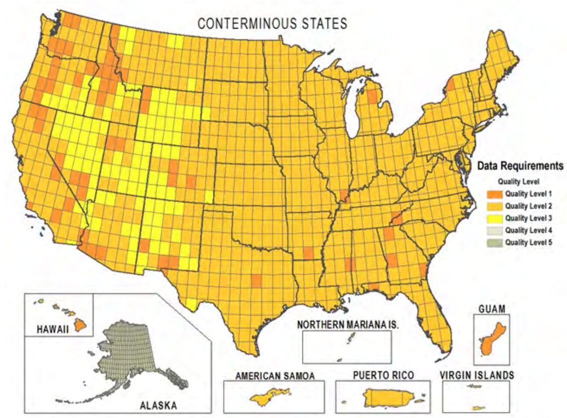


Figure 8.4. Scenario 2, mostly QL2 LiDAR nationwide with some QL1 and QL3 LiDAR; QL5 IFSAR for Alaska; 8-year acquisition period. This scenario has an optimal federal focus that benefits states and nongovernmental organizations also.

The data collected under Scenario 2 is optimized to provide the highest net benefit to the federal government or best meet the greatest amount of federal government program requirements in terms of Quality Level, with no area receiving less than QL3 in the conterminous U.S. An update frequency of 8 years was chosen because the 6-10 year update frequency consistently provided the best Benefit/Cost Ratio.

Scenario 2 would result in the following annual costs and benefits from the LiDAR and IFSAR data, excluding IT costs for data management and dissemination:

Total Annual Data Costs: $134.6M/year	**Total Annual Data Benefits: $698.9M/year**
Data Benefit/Cost Ratio: 5.194	**Net Annual Data Benefits: $564.4M/year**

Table 8.4 accumulates the annual costs and benefits over the 8-year lifecycle of Scenario 2, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.4. Scenario 2 Cumulative Lifecycle Costs and Benefits (in $ millions) over 8-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	8-Year Total
LiDAR Data Costs	$128	$256	$384	$512	$640	$767	$895	$1,024	**$1,024M**
IFSAR Data Costs	$7	$13	$20	$27	$33	$40	$47	$53	**$53M**
IT Costs	$20	$28	$36	$45	$64	$79	$92	$106	**$106M**
Combined Costs	$155	$298	$440	$583	$737	$886	$1,034	$1,183	**$1,183M**
Combined Benefits	$699	$1,398	$2,097	$2,796	$3,495	$4,194	$4,893	$5,591	**$5,591M**

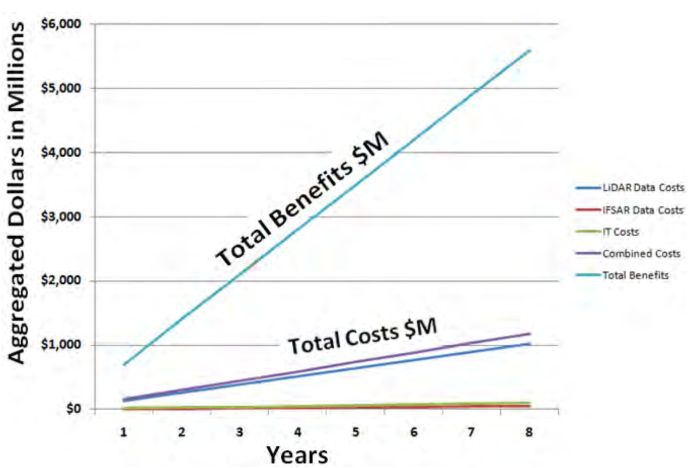


Figure 8.5. Scenario 2 aggregated costs and benefits over an assumed 8-year implementation period.

Figure 8.5 graphs the data in Table 8.4 which aggregates lifecycle costs over the 8-year acquisition period. Over 8 years, the total costs (in 2011 dollars) would be $1.024B for LiDAR, $53M for IFSAR (in Alaska) and $106M for IT costs – totaling $1.183B. Over that 8-year period, the total benefits would be $5.591B and the total net benefits would be $4.408B. When including IT costs, the overall Benefit/Cost Ratio is 4.726.

Scenario 2 Advantages

- Optimizes LiDAR Quality Levels to the variable needs of the federal government in different parts of the country. The data would also meet many state and nongovernmental Business Uses.
- Does not deliver data of higher accuracy and density than known to be needed by federal agencies.
- Complete nationwide coverage of mostly QL2 LiDAR in 8 years.
- While optimized to provide the highest federal B/C Ratio, Scenario 2 also provided the second highest lifecycle B/C Ratio (4.726) for all users combined.

Scenario 2 Disadvantages

- Nationwide coverage of LiDAR is non-uniform, with 70 QL1 LiDAR cells, 790 QL2 LiDAR cells, and 122 QL3 LiDAR cells. In Appendix F, Dewberry investigated several perceived anomalies pertaining to potential questions as to why some isolated cells justified QL1 LiDAR data compared with adjoining cells that justified QL2 or even QL3 LiDAR; the differences are usually subtle rather than clearly defined. Those looking at Figure 8.4 would inevitably wonder why only a single 1-degree cell of QL1 LiDAR per state is justified for TX, MI, AR, IL, NC, FL, NY and the MS/AL border; why only two QL1 LiDAR cells are justified for WY and UT, etc.
- The current USGS *LiDAR Guidelines and Base Specifications*, v13, are appropriate for QL3 LiDAR; v13 specifications would need to be modified slightly for the higher accuracy and higher density LiDAR for QL2 and QL1. Although the datasets would be compatible, with all three LiDAR Quality Levels included in Scenario 2, the LiDAR data would not be of uniform consistency.

8.4 Alternative Scenario 2A, 15-year Acquisition Period

If Scenario 2 data were instead acquired using a 15-year acquisition period instead of 8-years, the following data costs and benefits would apply for Scenario 2A:

Total Annual Data Costs: $71.8M/year	**Total Annual Data Benefits: $353.2M/year**
Data Benefit/Cost Ratio: 4.919	**Net Annual Data Benefits: $281.4M/year**

Table 8.5 accumulates the annual costs and benefits over the 15-year lifecycle of Scenario 2A, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.5. Scenario 2A Cumulative Lifecycle Costs and Benefits (in $ millions) over 15-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
LiDAR Data Costs	$68	$137	$205	$273	$341	$410	$478	$546
IFSAR Data Costs	$4	$7	$11	$14	$18	$21	$25	$28
IT Costs	$7	$14	$21	$28	$35	$42	$50	$57
Combined Costs	$79	$158	$237	$316	$394	$473	$552	$631
Combined Benefits	$353	$706	$1,060	$1,413	$1,766	$2,119	$2,472	$2,826
Costs and Benefits	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
LiDAR Data Costs	$614	$683	$751	$819	$887	$956	$1,024	**$1,024M**
IFSAR Data Costs	$32	$35	$39	$42	$46	$49	$53	**$53M**
IT Costs	$64	$71	$78	$85	$92	$99	$106	**$106M**
Combined Costs	$710	$789	$868	$947	$1,025	$1,104	$1,183	**$1,183M**
Combined Benefits	$3,179	$3,532	$3,885	$4,238	$4,592	$4,945	$5,298	**$5,298M**

Scenario 2A Comparison with Scenario 2

The average annual lifecycle costs for Scenario 2A ($79M/year) are nearly half the average annual lifecycle costs for Scenario 2 ($148M/year); however, the average annual lifecycle benefits from Scenario 2A ($353M /year) are also much lower than Scenario 2 ($699M/year). The average lifecycle B/C Ratio changes from 4.726 for Scenario 2 to 4.478 for Scenario 2A.

8.5 Scenario 3 – Uniform QL2 LiDAR, 8-year Acquisition Period

As shown in Figure 8.6, under Scenario 3, uniform QL2 LiDAR would be acquired nationwide except for QL5 IFSAR for Alaska. The acquisition period is 8 years.

Scenario 3 is a medium-cost alternative that would yield uniform QL2 LiDAR for 49 states and U.S. territories and QL5 IFSAR for Alaska; it offers high Net Benefits and a high Benefit/Cost Ratio.

Scenario 3 would result in the following annual costs and benefits from the LiDAR and IFSAR data, excluding IT costs for data management and dissemination:

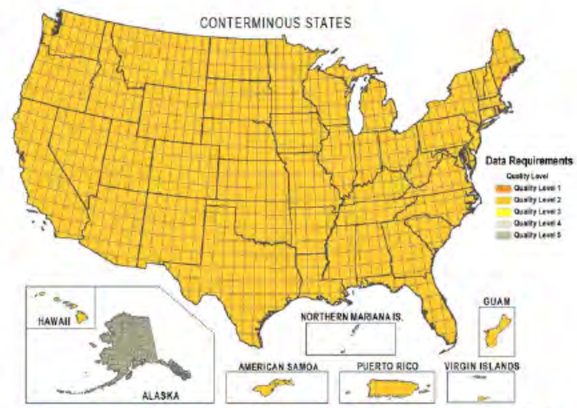


Figure 8.6. Scenario 3, Uniform QL2 LiDAR nationwide except QL5 IFSAR for Alaska; 8-year acquisition period; it has high net benefits and a high B/C Ratio – nearly the same as Scenario 2.

Total Annual Data Costs: $133.1M/year	**Total Annual Data Benefits: $689.9M/year**
Data Benefit/Cost Ratio: 5.184	**Net Annual Data Benefits: $556.8M/year**

Table 8.6 accumulates the annual costs and benefits over the 8-year lifecycle of Scenario 3, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.6. Scenario 3 Cumulative Lifecycle Costs and Benefits (in $ millions) over 8-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	8-Year Total
LiDAR Data Costs	$126	$253	$379	$506	$632	$759	$885	$1,012	**$1,012M**
IFSAR Data Costs	$7	$13	$20	$27	$33	$40	$47	$53	**$53M**
IT Costs	$20	$28	$36	$45	$64	$79	$92	$106	**$106M**
Combined Costs	$153	$295	$436	$577	$729	$877	$1,024	$1,171	**$1,171M**
Combined Benefits	$690	$1,380	$2,070	$2,760	$3,450	$4,139	$4,829	$5,519	**$5,519M**

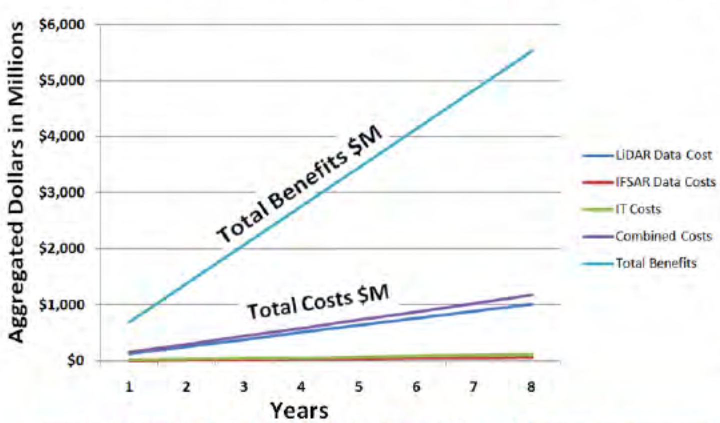


Figure 8.7. Scenario 3 aggregated costs and benefits over an assumed 8-year implementation period.

Figure 8.7 graphs the data in Table 8.6 which aggregates lifecycle costs over the 8-year acquisition period. The total costs (in 2011 dollars) would be $1.012B for LiDAR, $53M for IFSAR (in Alaska) and $106M for IT costs – totaling $1.171B in costs over 8 years. The total benefits would be $5.519B and the total net benefits would be $4.348B. When including IT costs, the overall Benefit/Cost Ratio is 4.713.

Scenario 3 Advantages

- Uniform QL2 LiDAR for 49 states and U.S. territories consistently produced to the USGS *LiDAR Guidelines and Base Specifications*, upgraded from v.13 specifications to cover QL2 data.
- Continuous uniformity in data quality.
- High B/C Ratio (4.713), nearly equal to that of Scenario 2 (4.726).
- As in scenario 2, uniform LiDAR data for 49 states would facilitate the development of applications software for nearly every Business Use based on known accuracy and density parameters.

Scenario 3 Disadvantages

- Parts of the country (mountains and deserts) may be mapped to higher quality standards than clearly needed based on requirements.

8.6 Alternative Scenario 3A, 15-year Acquisition Period

If data were acquired using a 15-year acquisition period instead of 8-years, the following data costs and benefits would apply for Scenario 3A:

Total Annual Data Costs: $71.0M/year	**Total Annual Data Benefits: $348.7M/year**
Data Benefit/Cost Ratio: 4.913	**Net Annual Data Benefits: $277.7M/year**

Table 8.7 accumulates the annual costs and benefits over the 15-year lifecycle of Scenario 3A, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.7. Scenario 3A Cumulative Lifecycle Costs and Benefits (in $ millions) over 15-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
LiDAR Data Costs	$67	$135	$202	$270	$337	$405	$472	$540
IFSAR Data Costs	$4	$7	$11	$14	$18	$21	$25	$28
IT Costs	$7	$14	$21	$28	$35	$42	$50	$57
Combined Costs	$78	$156	$234	$312	$390	$468	$547	$625
Combined Benefits	$349	$697	$1,046	$1,395	$1,744	$2,092	$2,441	$2,790
Costs and Benefits	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
LiDAR Data Costs	$607	$675	$742	$810	$877	$945	$1,012	**$1,012M**
IFSAR Data Costs	$32	$35	$39	$42	$46	$49	$53	**$53M**
IT Costs	$64	$71	$78	$85	$92	$99	$106	**$106M**
Combined Costs	$703	$781	$859	$937	$1,015	$1,093	$1,171	**$1,171M**
Combined Benefits	$3,138	$3,487	$3,836	$4,184	$4,533	$4,882	$5,231	**$5,231M**

Scenario 3A Comparison with Scenario 3

The average annual lifecycle costs for Scenario 3A ($78M/year) are nearly half the average annual lifecycle costs for Scenario 3 ($146M/year); however, the average annual lifecycle benefits from Scenario 3A ($349M/year) are also much lower than Scenario 3 ($690/year). The average B/C Ratio changes from 4.713 for Scenario 3 to 4.467 for Scenario 3A.

8.7 Scenario 4 – Mixed QL1/2/3 LiDAR, 8-year Acquisition Period

As shown in Figure 8.8, under Scenario 4, QL2 LiDAR would be acquired for most of the 48 conterminous states with some QL1 LiDAR (burnt orange) for Hawaii, Oregon, Texas, Illinois, Guam and isolated QL1 cells elsewhere, four QL3 LiDAR cells (yellow), plus QL5 IFSAR for 21 cells plus Alaska (grey).

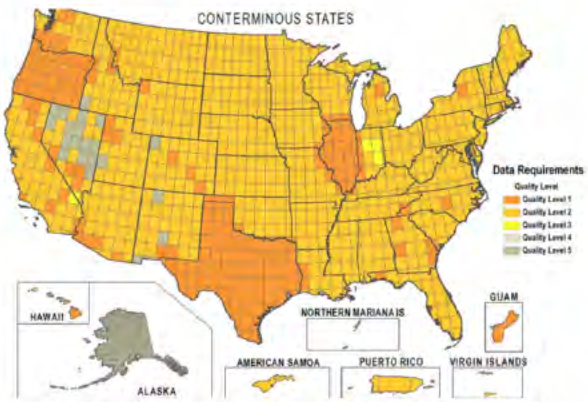


Figure 8.8. Scenario 4 Quality Levels, mostly QL2 LiDAR nationwide with larger QL1 areas; 8-year acquisition period. This scenario provides the highest net benefits for federal, state and nongovernmental users combined. Variations result from states that provided the highest dollar benefits for their specified Quality Levels.

Scenario 4 is the alternative that is optimized to maximize the Benefit/Cost Ratio for all federal/state/nongovernmental requirements combined. It also yields the highest combined net benefits and B/C Ratio of all scenarios and is the most expensive alternative.

Because dollar benefits were not provided by respondents for over half of the Functional Activities, the benefits are skewed towards those that did.

As determined through the Benefit Cost Analysis performed in this NEEA, this mix of QL5, QL3, QL2, and QL1 data of the 49 states and U.S. territories, and QL5 data of Alaska, acquired with an 8-year update frequency would result in the following annual costs and benefits:

Total Annual Data Costs: $147.3M/year	**Total Annual Data Benefits: $780.3M/year**
Data Benefit/Cost Ratio: 5.297	**Net Annual Data Benefits: $633.0M/year**

Table 8.8 accumulates the annual costs and benefits over the 8-year lifecycle of Scenario 4, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.8. Scenario 4 Cumulative Lifecycle Costs and Benefits (in $ millions) over 8-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	8-Year Total
LiDAR Data Costs	$141	$281	$422	$563	$703	$844	$985	$1,125	**$1,125M**
IFSAR Data Costs	$7	$13	$20	$27	$33	$40	$46	$53	**$53M**
IT Costs	$20	$28	$36	$45	$64	$79	$92	$106	**$106M**
Combined Costs	$168	$323	$478	$634	$800	$963	$1,124	$1,285	**$1,285M**
Combined Benefits	$780	$1,561	$2,341	$3,121	$3,901	$4,682	$5,462	$6,242	**$6,242M**

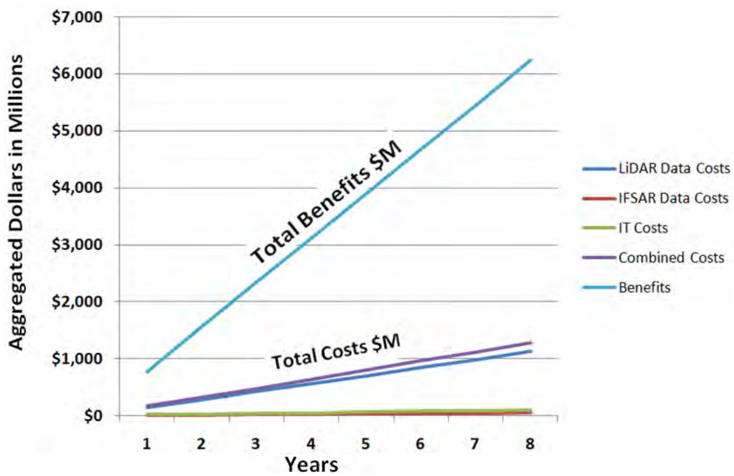


Figure 8.9. Scenario 4 aggregated costs and benefits over an assumed 8-year implementation period.

Figure 8.9 graphs the data in Table 8.8 which aggregates lifecycle costs over the 8-year acquisition period. Over 8 years, the total costs (in 2011 dollars) would be $1.125B for LiDAR, $53M for IFSAR (in Alaska) and $106M for IT costs – totaling $1.285B in costs over 8 years. Over that 8-year period, the total benefits would be $6.242B and the total net benefits would be $4.957B. When including IT costs, the overall Benefit/Cost Ratio is 4.858.

Scenario 4 Advantages

- Provides the highest total benefits, highest net benefits, and highest B/C Ratio of any scenario.
- Optimizes LiDAR Quality Levels to the variable needs of all partners in different parts of the country.

Scenario 4 Disadvantages

- Highest costs of any scenario.
- Provides four different Quality Levels, excluding Alaska, with some states clearly mapped to higher standards than others.
- Four states (HI, OR, TX, IL) would receive higher quality QL1 LiDAR data primarily because they estimated higher benefits of such data. This may be an artifact of the variability in state responses. If a national program was implemented using this scenario, respondents would be incentivized to provide or revise their estimated dollar benefits and the results could/would change as a result.
- Although fully compatible, the LiDAR data would be somewhat non-uniform since three Quality Levels would be produced.

8.8 Alternative Scenario 4A, 15-year Acquisition Period

If Scenario 4 were acquired using a 15-year acquisition period instead of 8-years, the following data costs and benefits would apply for Scenario 4A:

Total Annual Data Costs: $78.6M/year	**Total Annual Data Benefits: $394.1M/year**
Data Benefit/Cost Ratio: 5.016	**Net Annual Data Benefits: $315.5M/year**

Table 8.9 accumulates the annual costs and benefits over the 15-year lifecycle of Scenario 4A, including IT costs for data management and dissemination. All numbers are in 2011 dollars.

Table 8.9. Scenario 4A Cumulative Lifecycle Costs and Benefits (in $ millions) over 15-year Acquisition Period

Costs and Benefits	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
LiDAR Data Costs	$75	$150	$225	$300	$375	$450	$525	$600
IFSAR Data Costs	$4	$7	$11	$14	$18	$21	$25	$28
IT Costs	$7	$14	$21	$28	$35	$42	$50	$57
Combined Costs	$86	$171	$257	$343	$428	$514	$599	$685
Combined Benefits	$394	$788	$1,182	$1,576	$1,971	$2,365	$2,759	$3,153
Costs and Benefits	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Total**
LiDAR Data Costs	$675	$750	$825	$900	$975	$1,050	$1,125	**$1,125M**
IFSAR Data Costs	$32	$35	$39	$42	$46	$49	$53	**$53M**
IT Costs	$64	$71	$78	$85	$92	$99	$106	**$106M**
Combined Costs	$771	$856	$942	$1,028	$1,113	$1,199	$1,285	**$1,285M**
Combined Benefits	$3,547	$3,941	$4,335	$4,729	$5,123	$5,517	$5,912	**$5,912M**

Scenario 4A Comparison with Scenario 4

The average annual lifecycle costs for Scenario 4A ($86M/year) are nearly half the average annual lifecycle costs for Scenario 4 ($161M/year); however, the average annual lifecycle benefits from Scenario 4A ($394M /year) are also much lower than Scenario 4 ($780M/year). The B/C Ratio changes from 4.858 for Scenario 4 to 4.600 for Scenario 4A.

8.9 Comparison of Implementation Scenarios

Table 8.10 compares the lifecycle costs, benefits, net benefits, and B/C Ratios for these eight scenarios based on total costs and benefits, including data and infrastructure technology (IT) costs. Table 8.10 also compares the annual benefits for each scenario as a percentage of the total possible annual benefits that would be realized ($1.180B/year) if all *mission-critical* requirements were fully satisfied. Table 8.10 lists average annual costs and benefits because the IT costs vary by year, with higher costs the first year. Table 1.9 in the Executive Summary sorts this table so as to rank these scenarios by percent of critical needs satisfied.

Table 8.10. Lifecycle Benefit Cost Analysis Comparisons for Elevation Data + IT Costs Combined

All Scenarios include QL5 IFSAR for Alaska	Average Annual Costs	Average Annual Benefits	Average Annual Net Benefits	B/C Ratio	Total Possible Benefits Satisfied
Scenario 1, Uniform QL3 LiDAR, 25-years, focus on lowest costs	$35.1M	$148.4M	$113.3M	4.226	12.6%
Scenario 1A, Uniform QL3 LiDAR but 15-year update	$58.5M	$261.1M	$202.6M	4.461	22.1%
Scenario 2, QL1/2/3 LiDAR, 8 years, focus on federal requirements with highest B/C Ratio	$147.9M	$698.9M	$551.0M	4.726	59.2%
Scenario 2A, QL1/2/3 LiDAR but 15-year update	$78.9M	$353.2M	$274.3M	4.478	29.9%
Scenario 3, Uniform QL2 LiDAR, 8 years, focus on nationally uniform data with highest B/C Ratio	$146.4M	$689.9M	$543.5M	4.713	58.5%
Scenario 3A, Uniform QL2 LiDAR but 15-year update	$78.1M	$348.7M	$270.6M	4.471	29.5%
Scenario 4, QL1/2/3/5 data, 8 years, focus on highest combined net benefits for all users	$160.6M	$780.2M	$619.7M	4.858	66.1%
Scenario 4A, QL1/2/3/5 data but 15-year update	$85.7M	$394.1M	$308.4M	4.600	33.4%