Florida Statewide LiDAR Assessment

Prepared by:

Dewberry Consultants LLC

1000 N. Ashley Dr., Suite 801

Tampa, FL 33602

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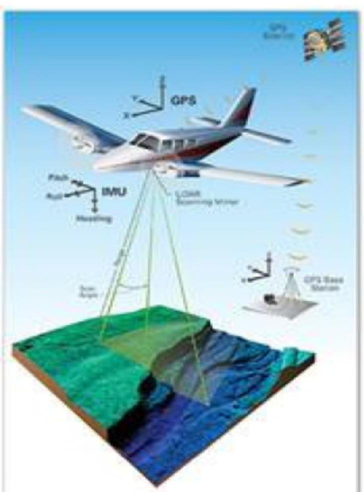

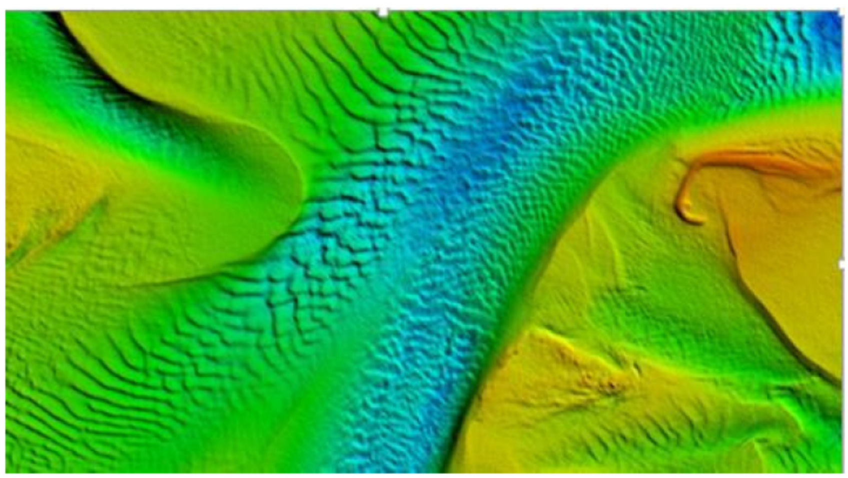

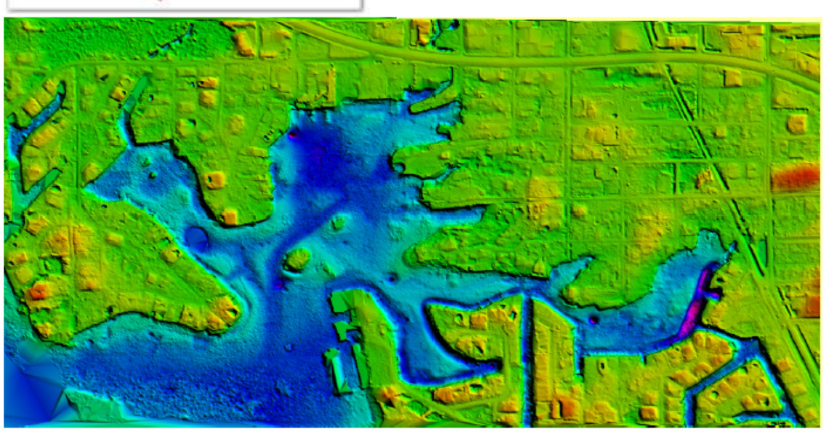

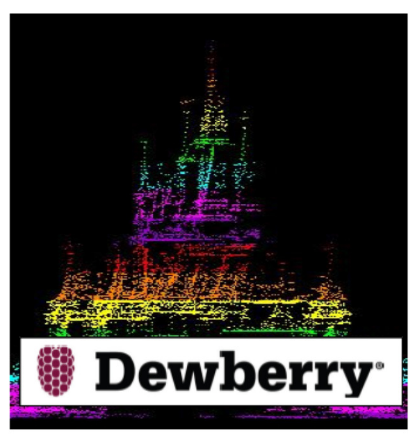

Table of Contents

Background

The 3D Elevation Program (3DEP)

In 2010, prompted by a growing appreciation for the wide applicability and inherent value of LiDAR, the U.S. Geological Survey (USGS) led a consortium of Federal agencies to conduct a National Enhanced Elevation Assessment (NEEA) study to quantify the costs and benefits of a national topographic LiDAR program. In 2012, Dewberry completed the NEEA study that evaluated 602 mission-critical requirements for enhanced elevation data nationwide; provided comprehensive benefit/cost analyses for multiple nationwide implementation scenarios for five potential elevation dataset Quality Levels (QL's) and six potential update frequencies; and computed the highest Net Benefits from QL2 LiDAR updated on an 8-year cycle. USGS called this "the most comprehensive benefit-cost analysis ever performed for any layer of The National Map."

In response to the NEEA study, the USGS established the 3D Elevation Program (3DEP) in 2013 as the interagency vehicle through which the NEEA recommendations could be realized. Subsequently, in 2014, the USGS published its *Lidar Base Specification*, Version 1.2 which provided detailed specifications for QL2 LiDAR as well as potential "buy-up" options for QL1 or QL0 LiDAR. This USGS specifications has since been endorsed by the U.S. Army Corps of Engineers (USACE), the Federal Emergency Management Agency (FEMA) and other organizations that previously had their own guidelines and specifications – thus enabling a nationally consistent 3DEP program for topographic LiDAR.

Table 1 shows how the three topographic LiDAR Quality Levels differ by vertical accuracy and point density. The 2nd and 3rd columns refer to the variable point densities, and the 4th, 5th and 6th columns pertain to vertical accuracy. RMSEz is the vertical Root Mean Square Error in non-vegetated terrain, a statistic used to compute the Non-vegetated Vertical Accuracy (NVA) at the 95% confidence level. In vegetated terrain, the Vegetated Vertical Accuracy (VVA) is computed at the 95th percentile, a different statistic used in vegetated terrain when bare-earth terrain elevation errors do not necessarily follow a normal error distribution. <u>Note that QL0 does not improve point density over QL1</u>.

Table 1. Topographic LiDAR Point Density and Vertical Accuracy

Quality Level (QL)	Aggregate Nominal Pulse Spacing (ANPS) (m)	Aggregate Nominal Pulse Density (ANPD) (points/m^2)	RMSE$_Z$ (non-vegetated) (cm)	NVA at 95% confidence level (cm)	VVA at 95th percentile (cm)
QL0	≤0.35	≥8	≤5	≤9.8	≤14.7
QL1	≤0.35	≥8	≤10	≤19.6	≤29.4
QL2	≤0.71	≥2	≤10	≤19.6	≤29.4

The USGS issues an annual Broad Agency Announcement (BAA) that provides detailed information on how to partner with the USGS and other Federal agencies to acquire high-quality 3D elevation data. The BAA process was established to make Federal partnerships with non-Federal partners more competitive, fair, and transparent. These efforts ultimately lead to cost efficiencies and a more consistent product. Applicants may choose to pay the cost difference for QL1 or QL0 LiDAR "buy-up" options when they can justify the need for higher accuracy or higher point density, as needed in portions of Florida.

The 3D Nation Initiative

The National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (USACE), Federal Emergency Management Agency (FEMA) and USGS are now planning a 3D Nation initiative to acquire accurate elevation foundation data from the tops of the mountains to the depths of the oceans.

To be competitive in the 21st century, our Nation must be GPS-enabled and ready with 3D maps to capitalize on all that GPS positioning accuracies offer, especially with regard to safety of marine navigation. The United States is GPS-enabled but lacks an accurate 3-dimensional foundation; in other words, our maps are holding us back. Critical decisions are made across our Nation every day that depend on elevation data, ranging from immediate safety of life and property to long term planning for infrastructure, sea-level change, and other factors. The 3D Nation will provide the most accurate foundation for mapping our changing world, and it will ensure access to an accurate, routinely updated, continuous elevation surface from the land to the depths of our waters. NOAA and USGS are currently planning for a 3D Nation Requirements and Benefits Study (3DNRBS) that will include requirements for and benefits from topographic LiDAR, bathymetric or topobathymetric LiDAR, and acoustic surveys (sonar). To multiply the benefits of elevation data and leverage the capacities of external data sources, USGS and NOAA will coordinate on the following integrated actions: (1) USGS' 3DEP program; (2) NOAA's Gravity for the Redefinition of the American Vertical Datum (GRAV-D) program; (3) NOAA's Shoreline Mapping Program; and (4) NOAA's Hydrographic Surveying Program. As with the NEEA, the 3DNRBS will consider six potential update frequencies for each bathymetric Quality Level: annually, 2-3 years, 4-5 years, 6-10 years, >10 years, or event driven.

Table 2 shows the 3D Nation's five bathymetric Quality Levels being considered for bathymetric or topobathymetric LiDAR.

Table 2. Bathymetric LiDAR Data Point Density and Vertical Accuracy

	$QL0_B$	$QL1_B$	$QL2_B$	$QL3_B$	$QL4_B$
Aggregate Nominal Pulse Spacing	≤0.7m	≤2.0 m	≤0.7 m	≤2.0 m	≤5.0 m
Aggregate Nominal Pulse Density	≥2.0 pts/m^2	≥0.25 pts/m^2	≥2.0 pts/m^2	≥0.25 pts/m^2	≥0.04 pts/m^2
Depth Examples (m)	**Vertical Accuracy of submerged elevations at 95% Confidence Level (cm)**				
0	25.0	25.0	30.0	30.0	50.0
10	26.1	26.1	32.7	32.7	51.7
20	29.2	29.2	39.7	39.7	56.4
Applications	Detailed site surveys requiring the highest accuracy and highest resolution seafloor definition; dredging and inshore engineering surveys; high-resolution surveys of ports and harbors		Charting surveys; regional sediment management; general bathymetric mapping; coastal science and management applications; change analysis; deep water surveys; environmental analyses		Recon/planning; all general applications not requiring higher resolution and accuracy

U.S. Interagency Elevation Inventory (USIEI)

At https://coast.noaa.gov/inventory/, NOAA and USGS maintain the U.S. Interagency Elevation Inventory (USIEI) of all publicly available LiDAR data to guide new data acquisition and avoid duplication. Figure 1 shows the status of topographic LiDAR in Florida as of March, 2017, including recent and ongoing topographic LiDAR task orders, summarized in Table 3, comprising over 20% of the land area of Florida. Thus, since 2015, over 20% of the state now colored green would have been amber or red. Similarly, Figure 2 shows the status of bathymetric/topobathymetric LiDAR in Florida.

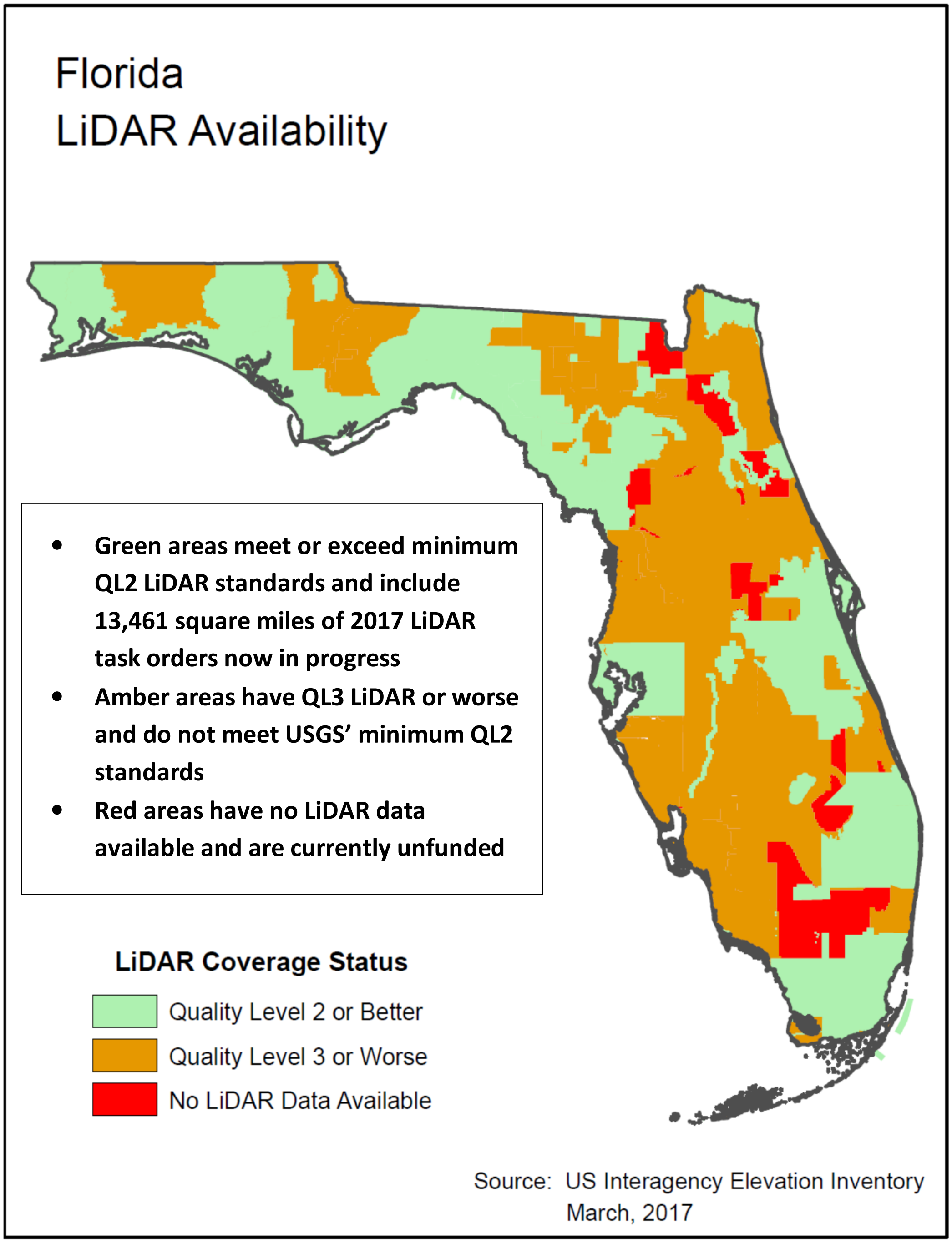

Figure 1. Florida Topographic LiDAR Coverage as of 2017

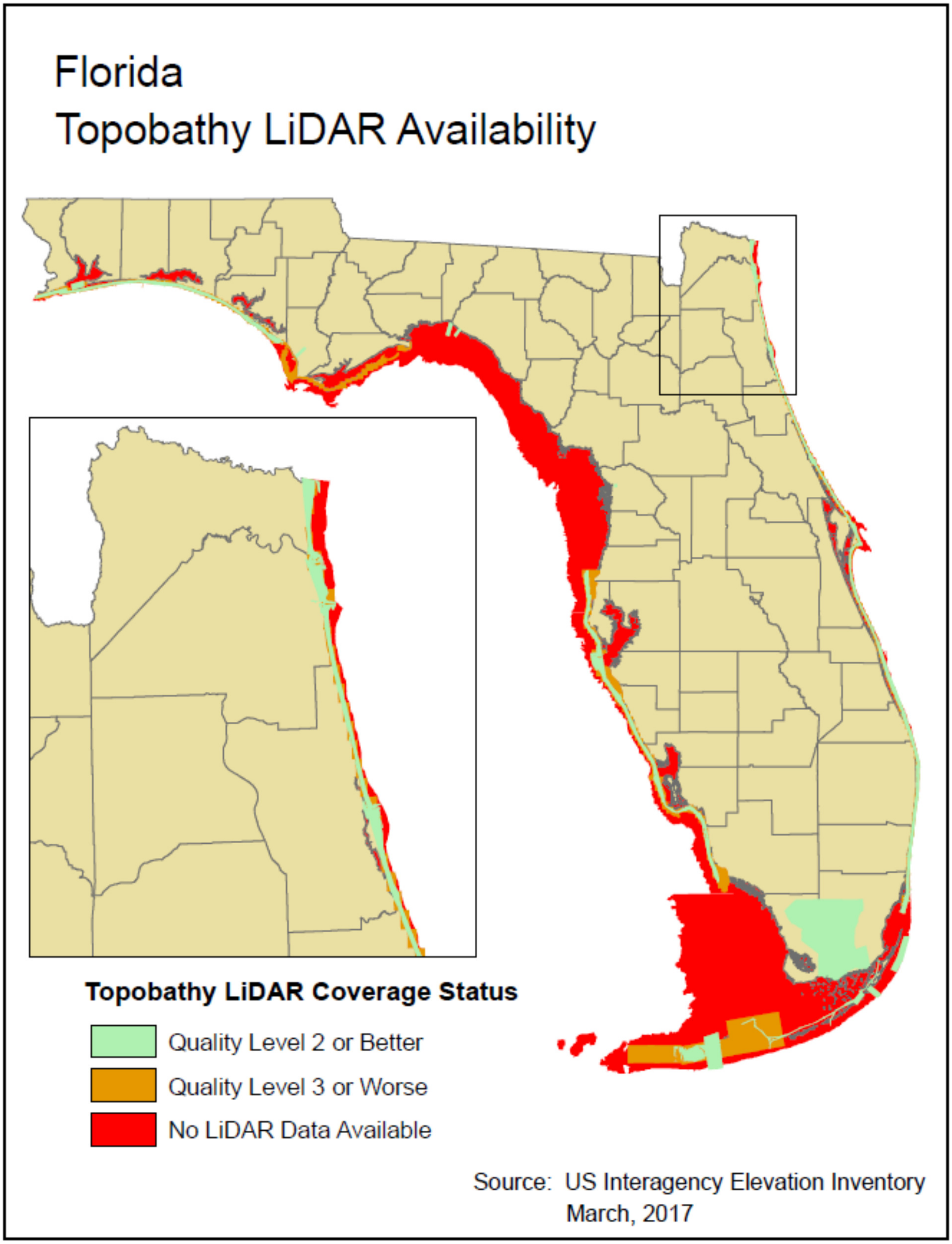

Figure 2. Florida Topobathymetric LiDAR Coverage as of 2017

Table 3. Recent USGS 3DEP LiDAR Investments in Florida

Project Name	Federal Contribution	State/Local/Tribal Contribution	Square Miles	Percent of State
Northwest Florida Water Management District	44.5%	55.5%	3,000	4.56
St. Johns River Water Management District	25.0%	75.0%	690	1.05
Suwannee River Water Management District	16.4%	83.6%	3,180	4.84
Palm Beach County	25.0%	75.0%	1,995	3.03
Osceola County	26.5%	73.5%	1,535	2.22
Martin County	49.0%	51.0%	545	0.83
Seminole Tribe of Florida, Brighton and Big Cypress Reservations	0%	100%	285	0.43
Everglades National Park – topobathymetric LiDAR	100%	0%	1,211	1.84
Southwest Florida Water Management District (Hillsborough County)	0%	100%	1,020	1.55
TOTALS			**13,461**	**20.47**

Florida Lessons Learned from the National Enhanced Elevation Assessment

The National Enhanced Elevation Assessment (NEEA), completed in 2012 by Dewberry for a consortium of government agencies led by the U.S. Geological Survey (USGS), analyzed all 50 states and U.S. territories by 1-degree x 1-degree cells (latitude and longitude) to determine which of five elevation data Quality Levels (QL's) and which of five update frequencies would be best for each cell. Dewberry initially analyzed requirements and benefits separately from three user groups: Federal agencies, states, and non-governmental organizations. The primary maps and summary statistics are at Appendix A. The overall lessons learned are summarized as follows:

1. If all three user groups acted alone, total annual costs would be $289M, total annual benefits would be $891, total annual net benefits would be $602M, and the Benefit/Cost ratio would be 3.079. Programs are inefficient when stakeholders do not work together to solve common needs.
2. By combining their programs, the total annual costs would be $213M, the annual benefits would be $1008M, the annual net benefits would be $795M, and the Benefit/Cost ratio would be 4.728; this is vastly superior in that costs are lower and benefits are higher from partnerships.
3. Based on its NEEA input, if Florida had acted alone, it could not justify any LiDAR Quality Level, but showed the best net benefits from QL5 IFSAR updated every 6-10 years. By combining all requirements and benefits, the NEEA concluded that QL2 LiDAR, updated on an 8-year cycle, would be the nationwide standard, with "buy-up" options for those with greater needs and willing to pay the cost difference.

Florida Statewide LiDAR Assessment: Project Management Plan

Scope of Work

On January 14, 2017, Dewberry received Order No. B05816 from the Florida Department of Environmental Protection (DEP) for six specific tasks for the Florida Statewide LiDAR Assessment to be completed by June 30, 2017. Dewberry immediately recognized that the schedule was extremely demanding and that a Project Management Plan would need to be expedited in order to complete the six tasks in the Scope of Work by the end of June:

1. Stakeholder identification, documenting business uses, and needs for repeated collections of elevation data
2. Data and information collection, including identifying datasets and products that meet future business needs
3. Assessment and review of emerging data collection technologies
4. Develop program implementation scenarios that address technical challenges, risks, benefits, costs including consistent quality assurance/quality control (QA/QC) and post-processing of collected data; calculate a return on investment analysis for the state of Florida for each scenario
5. Identify need and frequency of LiDAR coverage for the state of Florida, and
6. Identification of public and private partnerships for future funding, identification of funding models and strategies for increased awareness.

Executive Planning Committee

Throughout the planning stage, Dewberry worked with the ad hoc members of Florida's Executive Planning Committee, listed below:

- Dr. Jonathan Arthur, Director of the Florida Geological Survey and State Geologist
- Alan Baker, Florida Department of Environmental Protection
- Richard Butgereit, Florida Division of Emergency Management
- Dr. Alvan Karlin, Southwest Florida Water Management District
- Lou Driver, USGS Geospatial Liaison for Florida

Dewberry's management team included the following key participants:

- Dr. David Maune, PSM, Project Manager
- Sue Hoegberg, Deputy Project Manager and Geodatabase Manager

Dr. Maune and Ms. Hoegberg served in these same capacities for the NEEA study described above. They worked closely with the Florida Executive Planning Committee throughout the execution of this project, and they were assisted by other Dewberry Subject Matter Experts (SMEs) including Phil Thiel, Amar Nayegandhi, Josh Novac, Andrew Murdoch, Tom Copenhaver and Andrea Nelson.

Goal of the Florida Statewide LiDAR Assessment

At the kick-off meeting on February 2, 2017, when Dewberry presented its first draft Project Management Plan, it was established that the goal of the Florida Statewide LiDAR Assessment is to identify Business Uses and their requirements and benefits for topographic LiDAR, bathymetric LiDAR and/or topobathymetric LiDAR in the state of Florida when considering potential LiDAR Quality Levels and update frequencies; to determine implementation scenarios that would provide the highest Net Benefits, using benefit-cost analysis, when considering current and emerging LiDAR technologies; and to identify potential funding partnerships.

Florida's Strategic Principles

The Executive Planning Committee recognized that a statewide LiDAR acquisition plan is a moving target, with federal, regional, and local governments moving forward in some cases with individual, uncoordinated efforts, consistently changing the picture of available data. LiDAR technologies are rapidly changing – with new equipment and techniques frequently available to produce higher quality data. The Executive Planning Committee recommended that Dewberry's approach adhere to the following strategic principles, if possible:

- Large, seamless, temporally consistent areas should be prioritized. A persistent issue with existing high-resolution digital elevation data across the State of Florida is inconsistent elevations between existing projects which may have been collected under different seasonal conditions and years apart. Larger acquisition areas decrease these seams, minimizing inconsistencies.
- For scheduling LiDAR data acquisitions, the existing aerial photography 3-year flight schedule should be considered. Florida Department of Revenue coordinates the capture and distribution of high-resolution aerial photographs of approximately one third of the state each year according to the provisions of 195.022, FS. Improvement in the quality and value of both LiDAR and aerial photographs will occur when collected near the same time and under similar environmental conditions. LiDAR data collection should consider the existing aerial photography 3-year flight schedule.
- Adhere to USGS 3DEP (https://nationalmap.gov/3DEP) data specifications and criteria. The primary goal of 3DEP is to systematically collect enhanced elevation data in the form of high-quality LiDAR data over the country in compliance with USGS' LiDAR Base Specification V1.2 to ensure data consistency and quality. State data acquisitions should adhere to this specification. In addition to three topographic LiDAR Quality Levels shown in Table 1 above, these same specifications stipulate temporal requirements, requiring data to have been collected within the past 8 years. Over 80% of the data collected in the state does meet this temporal requirement.
- State funding should be used as a catalyst to stimulate joint partnerships between local government, regional government, and the private sector to pursue federal matching funds through USGS 3DEP. Over the past 3 years, USGS 3DEP has awarded over $23M nationwide to state and local governments in matching Federal funds in support of new LiDAR collection. Table 3 summarizes USGS 3DEP LiDAR investments in Florida (2015 – 2017 to date).

- Existing data gaps should be prioritized. As previously discussed, no LiDAR data has been acquired for over 8% of the state. These data gaps are interior to the state and cover large conservation lands, including national preserves and forests. Due to the sparse population of these areas, it may be tempting to prioritize higher populated areas. However – as approximately 92% of the state has existing data available, these areas continue to be overlooked, and the data gaps persist. State funding should be used to ensure that these data gaps are prioritized and a baseline, high-resolution digital elevation dataset established for these areas that may continue to be of low priority to other collection efforts.
- The Florida Department of Environmental Protection Statewide LiDAR Assessment, to be completed by June 2017, should be used to inform a final plan for statewide acquisition. Florida's LiDAR assessment should identify major business uses, LiDAR requirements, Net Benefits and priorities. This assessment should be used to develop and implement the final plan for acquisition.

Quality Levels and Update Frequencies

Florida's Executive Planning Committee and Dewberry agreed that we would establish requirements for and benefits of LiDAR based on the three standardized topographic LiDAR Quality Levels in Table 1 above, the five standardized bathymetric or topobathymetric LiDAR Quality Levels in Table 2 above, and six standardized Update Frequencies: (1) annual updates; (2) updated every 2-3 years; (3) updated every 4-5 years; (4) updated every 6-10 years; (5) updated at interval >10 years; or (6) event driven, i.e., updated only after an event such as a hurricane. Florida's Update Frequencies would then be the same as those used in the NEEA study, and the Quality Levels would be consistent with those of USGS, NOAA, USACE, FEMA and other Federal agencies.

Design Meetings

Dewberry held six design meetings between February 2, 2017 and April 7, 2017 with the Florida Executive Committee to finalize the Project Management Plan. The focus was on finalizing the list of LiDAR users and stakeholders to be invited to participate, as well as fine-tuning Dewberry's proposed SurveyMonkey® questionnaire so as to obtain thorough and credible information needed for analysis of LiDAR requirements and benefits. The Project Management Plan included the following Appendices:

- Appendix A was the contact information for Florida's list of LiDAR stakeholders to be invited to respond to the questionnaire. Dewberry and all members of the Executive Planning Committee (especially Jon Arthur) worked diligently for two months in an attempt to identify key LiDAR users and stakeholders.
- Appendix B was Dewberry's proposed stakeholder Instructions, and mitigation strategies to help avoid or reduce the impact of risks in the questionnaire process
- Appendix C was a tutorial of Frequently Asked Questions (FAQs), with specific FAQs hyperlinked to relevant questions to help respondents understand terminology used in the questionnaire.
- Appendix D provided examples of financial and other benefits from LiDAR data, also hyperlinked to the questionnaire.

- Appendix E was the proposed Questionnaire, with FAQ hyperlinks, designed to collect user requirements for enhanced topographic and/or bathymetric LiDAR.
- Appendix F was a sample Interview Guide for Dewberry to use, if necessary, to follow-up and resolve issues that result from questionnaire responses and to validate requirements and benefits.
- Appendix G was a summary of Mission Critical Activities (MCAs) relevant to Florida from the National Enhanced Elevation Assessment. Our goal was to re-capture as many of these requirements and benefits as possible for the current Florida Statewide LiDAR Assessment.

At the 6th design meeting on Friday, April 7, 2017, it was agreed that the Project Management Plan was complete and that the questionnaire process should begin the following week with the following actions:

- Monday, April 10th: Jonathan Arthur would send an email to stakeholders and users, telling them to expect a SurveyMonkey® request from dmaune@dewberry.com entitled: Florida Statewide LiDAR Assessment, asking them to complete the questionnaire by COB on Friday, April 21st (proposed cut-off date), and also asking them to ensure their emails are not blocked for access to SurveyMonkey®.
- Tuesday, April 11th: David Maune would send the SurveyMonkey® questionnaire to the final list of LiDAR stakeholders and users, asking for responses by COB on Friday, April 21st.
- Wednesday, April 12th: Jonathan Arthur would send follow-up emails asking if anyone did not receive their SurveyMonkey® request, and if not to check their deleted or junk mail folders.

Two more design meetings were held on April 24, 2017 and April 27, 2017 after initial results were in from the questionnaire responses. These meetings resulted in the addition of a few names to the list of stakeholders invited to participate in the questionnaire process.

Task 1: Stakeholder Identification/Documenting Business Uses

LiDAR Stakeholders and Users

Dewberry worked closely with all members of the Executive Planning Committee to develop an extensive list of topographic and bathymetric LiDAR stakeholders and LiDAR users throughout the state of Florida, to include names, organizations, job titles, email addresses and telephone contact information. One of the committee's jobs was to ensure that everyone understood the difference between a stakeholder and a technical user of LiDAR data:

- A stakeholder is a person entrusted with the success of a business or enterprise and who makes management decisions that impact business success or failure. A LiDAR stakeholder is more likely to understand costs, benefits and returns on investments (ROIs) from LiDAR.
- A LiDAR user is typically a GIS technician or analyst who solves technical problems using LiDAR but who does not necessarily worry about or understand costs, benefits, and ROI.
- Whereas LiDAR users can answer questions about their technical requirements for elevation data, any responses pertaining to costs or financial benefits must be reviewed and validated by a manager with some level of financial management responsibility, i.e., a stakeholder.

The Executive Planning Committee identified key LiDAR data stakeholders in Federal, state, and local government agencies, universities, and representatives of special LiDAR users such as geologists, soil scientists, hydrologists, foresters, farmers, floodplain and wetland managers, environmentalists, coastal zone and infrastructure managers, and urban and regional planners. Stakeholders were asked to self-select respondents to reduce duplicate submissions per agency.

Mission Critical Activities (MCAs) and Programs

A Mission Critical Activity (MCA) is defined as an activity or process that uses some form of LiDAR data, including derivative products, to accomplish a Business Use (BU). For example, within an emergency management program, hydrologic and hydraulic (H&H) modeling could be an MCA that supports a BU called Flood Risk Management, i.e., it would be mission-critical to have LiDAR data in order to perform H&H modeling required for floodplain mapping and flood risk management.

A program is a major component of an organization that has a well-defined mission and goals and which is supported by one or more MCAs.

Business Uses (BUs)

Dewberry and the Florida Executive Planning Committee agreed to utilize the 30 Business Uses (BUs) planned for the upcoming *3D Nation Requirements and Benefits Study*, accompanied by examples of user-defined MCAs linked to each BU. Stakeholders would be asked to define their MCAs in their own preferred terms, each linked to the most relevant BUs.

Jonathan Arthur and Alan Baker updated Dewberry's MCA examples to make them more relevant to Florida stakeholders. See Table 4.

Table 4. Standard Business Uses and Example Mission Critical Activities

Business Uses	Examples of Mission Critical Activities
BU 1 - Natural Resources Conservation	Conservation engineering. Soils and wetlands mapping and characterization. Modeling of biological and ecological systems. Erosion control. Rainfall penetration studies, impervious surfaces.
BU 02 - Water Supply and Quality	Fate and transport of contaminants. Pollution risk mitigation. Runoff and sedimentation analyses. Point- or non-point source pollution modeling. Management of contaminants and marine debris - point, non-point, vessel, and atmospheric pollution; spills; trash.
BU 03 – River and Coastal Ecosystem Management	Stream channel analysis and mapping. Stream bank erosion analysis. Aquatic and terrestrial species habitat management. Environmental management.
BU 04 - Coastal Zone Management	Analysis of coastal erosion and inundation. Hurricane storm surge and wind damage modeling and assessment. Coastal hazard modeling and mapping. Coastal hazard mitigation. Tsunami modeling. Land use and environmental planning. Oil spill modeling. Coastal resiliency. Littoral zone including dunes and beaches.
BU 05 – Forest Resources Management	Forest health assessment. Determination of standing inventory of forest resources. Prescribed burn planning. Harvest systems planning.
BU 06 – Rangeland Management	Assessment of rangeland health. Mapping for soil erosion potential due to grazing.
BU 07 – Wildlife and Habitat Management	Conservation planning for wildlife refuges and marine sanctuaries. Conservation of critical habitats. Management of diverse migratory bird habitats, coral reef and coral communities, marine mammals, protected fish species, and trust resources.
BU 08 – Agriculture and Precision Farming	Farm pond design. Irrigation system design. Detailed site analysis to support precision farming. Analysis of farm sedimentation and runoff. Calibration of fertilizer application, fertilizer management and irrigation planning. Optimized terraforming.
BU 09 – Aquaculture and Fish Farming	Management of fisheries. Sustainable aquaculture. Estuary mapping and resilience.
BU 10 – Geologic Resource Assessment and Hazard Mitigation	Geologic mapping and analysis. Sinkhole and steephead mapping monitoring and analysis. Identification of geomorphologic units. Landslide hazard mapping and assessment. Karst mapping, including springs and caves. Aquifer recharge.
BU 11 – Resource Mining	Sediment management. Monitoring sand as a local resource. Offshore mineral extraction. Open mine volume computations. Stockpile analysis. Environmental impact assessment and site restoration.
BU 12 – Renewable Energy Resources	Alternate energy development – solar, tidal, wind, wave, and ocean current. Assessment of rooftops for solar energy potential. Analysis of wind energy potential and turbine placement. Low head power potential for hydropower.

Business Uses	Examples of Mission Critical Activities
BU 13 – Oil and Gas Resources	Oil and gas exploration and production. Pipeline and route selection. Facility siting to mitigate geologic hazards. Construction planning. Environmental impact assessment and mitigation. Regulatory compliance.
BU 14 - Cultural Resources Preservation and Management	Discovery and analysis of underwater archaeological and historical cultural sites. Site protection and preservation planning. Discovery and analysis of Native American and other historical cultural sites and subsistence activities.
BU 15 – Flood Risk Management	Flood risk modeling and mapping of riverine and coastal areas. Dam/dike/levee safety analysis. Emergency management. Flood forecasts.
BU 16 – Sea Level Rise and Subsidence	Modeling and mapping the effects of sea level rise or subsidence. Population and economic vulnerability assessments. Coastal inundation and infrastructure assessment.
BU 17 – Wildfire Management, Planning, and Response	Determination of forest fuel and fire susceptibility. Fire behavior modeling to support wildfire suppression activities. Wildland/urban interface building identification. Post fire analysis to determine landslide prone areas.
BU 18 – Homeland Security, Law Enforcement, and Disaster Response Emergency Management	Infrastructure and border protection. Coastal search and rescue. Population dynamics. Emergency fuel supply and movement. Line of sight analysis in urban areas. Flood risk analysis resulting from acts of terrorism.
BU 19 – Land Navigation and Safety	Road/railroad route selection and maintenance. Slope analysis for autonomous cars. GPS navigation visualization.
BU 20 – Marine and Riverine Navigation and Safety	Nautical charting. Bathymetric measurements of near-shore submerged coastal topography. Identification of hazards to navigation in ports, rivers, navigable waterways. Sediment management at coastal navigation projects. Precision marine navigation.
BU 21 – Aviation Navigation and Safety	Determination of in-flight hazards and path obstructions. Aeronautical charting. Runway construction and repair.
BU 22 – Infrastructure and Construction Management	Marine construction. Bridge design and construction. Engineering and construction of dams, levees, dikes, reservoirs, and coastal structures. Shipyard and port construction. Water, sewer, or power line planning and vegetation analysis. Pump, drain and well placement. Stormwater modeling. Cut and fill analysis for earth-moving. Building site analysis. Road infrastructure.
BU 23 – Urban and Regional Planning	Land development and zoning. Municipal mapping of building footprints and elevations. Stormwater management. Port resilience planning. Parks and transportation planning. Virtual city creation. Urban ecology planning.
BU 24 – Health and Human Services	Health emergency response. Habitat modeling and disease prevention. Defining boundaries for health advisories for swimming and fishing. Marine-based bio products and pharmaceuticals. Public health and safety. Prevention of waterborne diseases.

Business Uses	Examples of Mission Critical Activities
BU 25 – Real Estate, Banking, Mortgage, and Insurance	Assessment of risk for natural hazards (e.g., sinkholes, flooding) to inform insurance policy rates and the determination of mandatory insurance. Building permit compliance.
BU 26 – Education K-12 and Beyond; Basic Research	Development of 3-D visualizations to help students understand the Earth they live on. Understanding of continental-scale climate change impacts. Ocean science. Ocean education. Scientific research. Data dissemination. Development of training simulators.
BU 27 – Recreation	Planning and development of recreational facilities such as rafting, boating, swimming, diving, and fishing areas, springs and golf courses. Location-based products and services such as maps and guides. Tourism. Trail and vista site planning. Orienteering.
BU 28 - Telecommunications	Telecommunication tower site selection. Design of radio and radar systems. Interference analysis. Path profiles. Undersea telecommunication route selection and deployment.
BU 29 - Military	Tactical military operations. Strategic defense. Amphibious landings and logistics over-the-shore. Operation of ships and submarines. Weapons system testing. Management of flight facilities and offshore launch or target areas.
BU 30 – Maritime and Land Boundary Management	Delimitation of legal and other coastal boundaries, inland boundaries, ordinary high water lines (OHWL).

Questionnaire and Geodatabase

The Questionnaire was included as Task 1.B in Dewberry's Project Management Plan. The final Questionnaire was Appendix E of that Plan.

Dewberry developed the Questionnaire so that answers could populate the study Geodatabase, to include polygons for each MCA's geographic area requirements. Question 8 of the Questionnaire asked respondents to choose from a pick list of geographic AOIs: (a) Florida statewide, (b) one or more Water Management Districts, (c) one or more Florida Regional Planning Councils, (d) one or more counties or cities, (e) one or more Hydrologic Unit Codes (HUCs), (f) federally-owned lands in Florida, (g) Florida state-owned lands, or (9) user-defined polygons or shapefiles submitted via SeaSketch. Dewberry also provided polygons for near-shore bathymetry out to 10 meter depths (except for 20 meter depths in Monroe County) where bathymetric or topobathymetric LiDAR may be expected to work well because of water clarity.

Each geographic polygon in the geodatabase is directly linked to all LiDAR user/stakeholder requirements and benefits information from the questionnaire. This geographic information is essential for the implementation of various scenarios and their benefit/cost analyses to determine what LiDAR Quality Levels and Update Frequencies will provide the highest Net Benefits.

Task 2: Data Collection/Identify Datasets to Meet Future Business Needs

Questionnaire Process

On Tuesday, April 11, 2017, the SurveyMonkey® questionnaire was sent by Dewberry to 185 invitees, specifying a closing date of Friday, April 21, 2017. This was the official start of Task 2. Jon Arthur followed up on Wednesday, April 12, 2017, asking invitees to respond if they had not received the invitation from Dewberry and to check their junk mail folders if they had not seen their invitation. This questionnaire included dozens of hyperlinks to Frequently Asked Questions (FAQs) and example benefits.

On Monday, April 24, 2017, during Design Meeting No. 7, Dewberry reported that only 38 of 185 invitees had completed their questionnaires and 22 had partially completed their questionnaires. It was agreed that Dewberry would keep the questionnaire open through COB on Wednesday, April 26th, and Jon Arthur would send reminder emails to those who partially completed the questionnaire and those who did not even partially complete the questionnaire and may not have even seen the questionnaire. Furthermore, Dave Maune and several members of the Executive Planning Committee volunteered to contact invitees they knew to personally to encourage them to complete their questionnaire.

On Thursday, April 27, 2017, after learning that many SurveyMonkey® requests had gone directly into junk mail folders, or were deleted outright because of spam filters used by many agencies for security purposes, Dewberry provided direct links to the questionnaire to those who had not responded. This resulted in 13 new responses within 24 hours.

On Friday, April 28, 2017, during the last Design Meeting No. 8, Dewberry reported that 81 responses had been received from our original SurveyMonkey® requests, several with multiple MCAs, plus the 13 new responses from Dewberry's initiative in providing a direct link to the questionnaire. Unfortunately, a significant number of responses provided contact information only for respondents that did not enter even their LiDAR requirements information, making their input unusable for any Cost-Benefit Analysis to follow.

The direct link was not used initially because of concerns that a direct link would allow broad and free dissemination of the questionnaire to others and could result in "stacking the deck" with duplicate benefits; but in the end responses were received only from personnel who had been invited to submit for their individual programs.

Dewberry subsequently decided that it could and should keep the SurveyMonkey® site open until Friday, May 19, 2017. In the interim, a few additional personnel were invited, bringing the total to 190.

Data Validation Process

Between April 24th and May 19th, Dewberry performed the data validation process in multiple steps:

1. Converted the SurveyMonkey® responses into a master spreadsheet that included individual MCA responses for each SurveyMonkey® question.
2. Used the master spreadsheet to draft Mission Critical Activity (MCA) Summary Sheets for each MCA that had been submitted
3. Reviewed each MCA Summary Sheet for missing or incomplete information or inconsistencies.

4. Sent dozens of emails to respondents, with their draft MCA Summary Sheets, to collect missing information if possible and to give respondents the opportunity to comment on their Summary Sheets if they wished to change anything.
5. Made dozens of telephone calls and interviewed respondents to resolve inconsistencies, clarify responses, and split future annual dollar benefits into percentages from topographic LiDAR and bathymetric LiDAR.
6. Sent MCA Summary Sheet templates to 38 addressees who had previously downloaded NOAA bathymetric LiDAR of Florida and had indicated that they would be receptive to follow-up queries. Dewberry asked if they could summarize their LiDAR requirements and benefits by completing the MCA form. Unfortunately we received no responses from this request.
7. Deleted MCA responses that did not at least specify their LiDAR requirements. If LiDAR users or stakeholders could not specify their geographic area requirements, quality levels and update frequencies, their input was considered unusable for the Cost-Benefit Analysis process to follow.
8. Prepared final MCA Summary Sheets for the remaining 97 MCAs.

Questionnaire Metrics

By close of business on Friday, May 19, 2017, the following metrics summarize overall responses to the questionnaires:

- 190 emailed invitations to complete the questionnaire for topographic and/or bathymetric LiDAR requirements and benefits
- 104 respondents opened the questionnaire and provided contact information, but many of these did not proceed to the part where they specified their LiDAR requirements information (geographic area of interest, LiDAR Quality Levels and Update Frequencies)
- 78 provided their LiDAR requirements for 97 Mission Critical Activities (MCAs)
- Annual topographic LiDAR dollar benefits were estimated for 64 of the 97 MCAs; and annual bathymetric LiDAR dollar benefits were estimated for 48 of the 97 MCAs; no dollar benefits were estimated for 33 MCAs.
- All five Water Management Districts provided dollar benefits.
- Six of 10 Regional Planning Councils submitted LiDAR requirements, but only two of these were able to estimate dollar benefits.
- Ten of 67 counties submitted LiDAR requirements, and eight of these estimated dollar benefits.
- Of the 97 MCAs, regardless of whether or not dollar benefits were estimated, 50 cited major operational benefits for time and cost savings, 52 cited major operational benefits for improved mission compliance, 54 cited major customer service benefits for improved products and services, and 37 cited major customer service benefits for improved response or timeliness.

Summary of Questionnaire Responses

Responses to selected questions are summarized in Tables 5 through 25.

Table 5. Type of Organization (Question 2)

Question 2. Which type of organization do you represent? Please select one of the following seven options.		
Answer Options	**Response Percent**	**Response Count**
Federal Agency or Commissions	18.6%	18
Statewide agency	23.7%	23
Regional, county, or city government	38.1%	37
Tribal government	0.0%	0
Not-for-Profit	1.0%	1
Private or Commercial	8.2%	8
University	10.3%	10
	Total	**97**

Table 6. LiDAR User or Stakeholder (Question 3)

Question 3. When compared with the definitions in FAQ #1 do you consider yourself a LiDAR user, a LiDAR stakeholder, or both?		
Answer Options	**Response Percent**	**Response Count**
LiDAR user only	26.8%	26
LiDAR stakeholder only	2.1%	2
Both a LiDAR user and LiDAR stakeholder	71.1%	69
	Total	**97**

Table 7. Primary, Secondary and Tertiary Business Uses (Question 5)

Question 5. What is your 1st (primary) Business Use for this Mission Critical Activity (MCA)? You must select only one 1st (primary) most relevant Business Use. You may optionally select a 2nd (secondary) and 3rd (tertiary) Business Use that applies to your MCA, but your reported benefits will be aggregated with the primary Business Use you select. After this section is completed, you will be allowed to enter up to two additional MCAs that may have totally different Business Uses.				
Answer Options	**1st**	**2nd**	**3rd**	**Response Count**
BU 1 - Natural Resources Conservation:	11	10	3	24
BU 2 - Water Supply and Quality:	9	8	2	19
BU 3 – River and Coastal Ecosystem Management	3	5	6	14
BU 4 - Coastal Zone Management	6	7	9	22
BU 5 – Forest Resources Management	5	2	1	8
BU 6 – Rangeland Management	0	0	0	0
BU 7 – Wildlife and Habitat Management	4	6	4	14
BU 8 – Agriculture and Precision Farming	2	1	0	3
BU 9 – Aquaculture and Fish Farming	0	0	0	0
BU 10 – Geologic Resource Assessment	2	2	3	7

Question 5. What is your 1st (primary) Business Use for this Mission Critical Activity (MCA)? You must select only one 1st (primary) most relevant Business Use. You may optionally select a 2nd (secondary) and 3rd (tertiary) Business Use that applies to your MCA, but your reported benefits will be aggregated with the primary Business Use you select. After this section is completed, you will be allowed to enter up to two additional MCAs that may have totally different Business Uses.

Answer Options	1st	2nd	3rd	Response Count
BU 11 – Resource Mining	0	2	1	3
BU 12 – Renewable Energy Resources	0	0	0	0
BU 13 – Oil and Gas Resources	1	0	0	1
BU 14 - Cultural Resources Preservation and Mgt.	2	0	0	2
BU 15 – Flood Risk Management	23	6	6	35
BU 16 – Sea Level Rise and Subsidence	4	9	6	19
BU 17 – Wildfire Management, Planning, Response	2	2	1	5
BU 18 – Homeland Security, Emergency Mgt.	1	2	2	5
BU 19 – Land Navigation and Safety	0	2	0	2
BU 20 – Marine and Riverine Navigation and Safety	7	0	1	8
BU 21 – Aviation Navigation and Safety	0	1	1	2
BU 22 – Infrastructure and Construction Management	7	5	4	16
BU 23 – Urban and Regional Planning	3	4	5	12
BU 24 – Health and Human Services	0	0	1	1
BU 25 – Real Estate, Banking, Mortgage, Insurance	0	0	3	3
BU 26 – Education K-12 and Beyond; Basic Research	2	0	0	2
BU 27 - Recreation	0	1	2	3
BU 28 - Telecommunications	0	0	0	0
BU 29 - Military	0	0	0	0
BU 30 – Maritime and Land Boundary Management	3	1	0	4
No Response	0	21	36	57
Total	97	97	97	

Table 8. Geographic Area Requirements (Question 8)

Question 8. In this section, please identify your geographic area requirements for the Mission Critical Activity (MCA) described above. [FAQ #3 provides guidance on how to find out what LiDAR data are already available in Florida]. We need to understand geographic area requirements for each MCA. Questionnaire respondents are encouraged to describe their geographic (area of coverage) requirements using the provided administrative and watershed boundary pick lists. Alternatively, shapefiles for your geographic areas of interest may be provided. My geographic area requirements are (pick one of the following):

Answer Options	Response Percent	Response Count
Florida statewide	46.4%	45
One or more Water Management Districts	15.5%	15
One or more Florida Regional Planning Councils	6.2%	6
One or more counties	20.6%	20
One or more HUC-4 or HUC-8 Watersheds	2.1%	2

Question 8. In this section, please identify your geographic area requirements for the Mission Critical Activity (MCA) described above. [FAQ #3 provides guidance on how to find out what LiDAR data are already available in Florida]. We need to understand geographic area requirements for each MCA. Questionnaire respondents are encouraged to describe their geographic (area of coverage) requirements using the provided administrative and watershed boundary pick lists. Alternatively, shapefiles for your geographic areas of interest may be provided. My geographic area requirements are (pick one of the following):		
Answer Options	**Response Percent**	**Response Count**
Federally-owned lands, State-owned lands, or select large land holding agencies	4.1%	4
None of the above; I will provide my own polygon or shapefile via SeaSketch	2.1%	2
To 10' depth contour	3.1%	3
	Total	**97**

Table 9. Areas where LiDAR data are needed (Question 9)

Question 9. For your MCA, how would you characterize the area for which you need LiDAR data? Check all that apply.		
Answer Options	**Response Percent**	**Response Count**
Inland topography	86.6%	84
Inland bathymetry (including streams, lakes, springs, Florida Intracoastal Waterway)	68.0%	66
Beaches and dunes	49.5%	48
Littoral zone (intertidal zone)	44.3%	43
Nearshore bathymetry <10m deep	45.4%	44
Offshore bathymetry >10m deep	23.7%	23

Table 10. Type areas mapped in 3D (Question 10)

Question 10. For your Mission Critical Activity, what do you need/want to measure in 3D? Check all that apply.		
Answer Options	**Response Percent**	**Response Count**
Bare earth ground	87.6%	85
Tops of buildings, structures, objects	40.2%	39
Power lines	15.5%	15
Tops of vegetation	40.2%	39
Vegetation subcanopy/understory	43.3%	42
Inland bathymetry	61.9%	60
Nearshore bathymetry	46.4%	45
Offshore bathymetry	23.7%	23

Table 11. Required topographic LiDAR Quality Levels (Question 11)

Question 11. Consistent with the nationwide 3D Elevation Program (3DEP), what topographic LiDAR Quality Level (QL) do you require for your Mission Critical Activity? Check one QL only, chosen from the table below. See FAQ #6 which explains 3DEP terminology and explains how to determine ANPS/ANPD.

Answer Options	Response Percent	Response Count
QL0: RMSEz ≤ 5 cm and aggregate nominal pulse density ≥8 points/square meter	17.5%	16
QL1: RMSEz ≤ 10 cm and aggregate nominal pulse density ≥8 points/square meter	37.1%	37
QL2: RMSEz ≤ 10 cm and aggregate nominal pulse density ≥2 points/square meter (this is the current standard for the nationwide 3D Elevation Program (3DEP) that satisfies the USGS Lidar Base Specification	43.3%	42
Enter comments if desired.	2.1%	2
	Total	**97**

Table 12. Required topographic LiDAR Update Frequencies (Question 12)

Question 12. For the Mission Critical Activity that you specified, how frequently does the topographic LiDAR data need to be updated to satisfy your requirements? See FAQ #7.

Answer Options	Response Percent	Response Count
Annually	10.3%	10
2-3 years	26.8%	26
4-5 years	30.9%	30
6-10 years	15.5%	15
>10 years	2.1%	2
Event driven – Needs not met by a cyclic data acquisition program	13.4%	13
No response	1.0%	1
	Total	**97**

Table 13. Required standard 3DEP topographic LiDAR deliverables (Question 13)

Question 13. For your Mission Critical Activity, what standard 3DEP topographic and topobathymetric LiDAR deliverables do you require? Check all that apply. See FAQ #8 for explanations.

Answer Options	Response Percent	Response Count
Raw point cloud data	49.5%	48
Classified point cloud data	72.2%	70
Bare earth surface, raster Digital Elevation Model (DEM)	85.6%	83
Seamless topobathymetric DEM	53.6%	52
Breaklines for standard hydro-flattening (topographic LiDAR only)	51.5%	50
Intensity imagery	36.1%	35
Survey Control	58.8%	57
Metadata	76.3%	74
Project Report	62.9%	61

Table 14. Required non-standard “buy-up” options (Question 14)

Question 14. For your Mission Critical Activity, what non-standard topographic and topobathymetric LiDAR “buy-up” options do you require? Check all that apply. See FAQ #9.		
Answer Options	**Response Percent**	**Response Count**
Digital Surface Model (DSM), hydro-flattened	38.1%	37
Digital Surface Model (DSM), with LiDAR-derived water surface	32.0%	31
LiDAR Waveform data	15.5%	15
Hydro-enforced Digital Terrain Model (DTM)	27.8%	27
2-D building footprints	23.7%	23
3-D building footprints	18.6%	18
Power lines, poles, and towers	12.4%	12
Additional LAS classes 3, 4, 5 for low, medium, and high vegetation	20.6%	20
Additional LAS classes 10 and 11 for railroad and road surfaces	11.3%	11
Automated Low Confidence Area polygons	28.9%	28
Manual Low Confidence Area polygons	13.4%	13
None	14.4%	14
Other, including enhanced breaklines (explain below)	17.5%	17

Table 15. Required LiDAR derivatives (Question 15)

Question 15. For your Mission Critical Activity, which of the following LiDAR derivatives do you need, in addition to the raster DEM, hydro breaklines and other standard deliverables in Question 13? Check all that apply. See FAQ #10.		
Answer Options	**Response Percent**	**Response Count**
Triangulated Irregular Network (TIN) or Esri Terrain	20.6%	20
Contours	49.5%	48
Hillshades	29.9%	29
Slope maps	18.6%	18
Aspect maps	8.2%	8
Curvature maps	7.2%	7
Cross sections	23.7%	23
Classified submerged objects	19.6%	19
None	28.9%	28
Other (please specify)	4.1%	4

Table 16. Required topographic LiDAR beach profile depth (Question 16)

Question 16. How far down the beach profile do you need topographic LiDAR data to support your Mission Critical Activity? Choose one only. See FAQ #11.		
Answer Options	**Response Percent**	**Response Count**
To Mean High Water (MHW)	23.7%	23
To Mean Lower Low Water (MLLW)	32.0%	31
Below MLLW	20.6%	20
None	1.0%	1
No response	22.7%	22

Question 16. How far down the beach profile do you need topographic LiDAR data to support your Mission Critical Activity? Choose one only. See FAQ #11.		
Answer Options	Response Percent	Response Count
	Total	97

Table 17. Required bathymetric LiDAR beach profile depth (Question 16a)

Question 16a. How far down the beach profile do you need bathymetric or topobathymetric LiDAR data to support your Mission Critical Activity? Choose one only. See FAQ #11.		
Answer Options	Response Percent	Response Count
To Mean High Water (MHW)	14.4%	14
To Mean Lower Low Water (MLLW)	11.3%	11
Below MLLW	39.2%	38
None	33.0%	32
No response	2.1%	2
	Total	97

Table 18. Requirement to detect submerged objects for nautical charting (Question 17)

Question 17. Do you need to detect submerged objects for nautical charting? See FAQ #12.		
Answer Options	Response Percent	Response Count
Yes	16.5%	16
No	80.4%	78
I don't know	3.1%	3
	Total	97

Table 19. Required bathymetric/topobathymetric LiDAR Quality Levels (Question 18)

Question 18. What bathymetric or topobathymetric LiDAR Quality Level (QLB) do you require for your Mission Critical Activity? Check one QLB only, chosen from the table below. Note that QL0B and QL1B are equivalent to the IHO Special Order standard, and the vertical accuracy specification for QL4B is equivalent to the IHO Order 1 standard for vertical accuracy. See FAQ #6.		
Answer Options	Response Percent	Response Count
QL0B	13.4%	13
QL1B	12.4%	12
QL2B	26.8%	26
QL3B	7.2%	7
QL4B	6.2%	6
Not applicable (topographic LiDAR only)	34.0%	33
	Total	97

Table 20. Required bathymetric/topobathymetric LiDAR Update Frequencies (Question 19)

Question 19. For the Mission Critical Activity that you specified, how frequently does the bathymetric or topobathymetric LiDAR data need to be updated to satisfy your requirements? (Note that Question 12 previously asked a similar question pertaining to update frequency for topographic LiDAR.) See FAQ #7.		
Answer Options	**Response Percent**	**Response Count**
Annually	5.2%	5
2-3 years	18.6%	18
4-5 years	18.6%	18
6-10 years	11.3%	11
>10 years	2.1%	2
Event driven – Needs not met by a cyclic data acquisition program	12.4%	12
Not applicable (topographic LiDAR only)	32.0%	31
	Total	**97**

Table 21. Importance of seamless integration of topo, bathy and topobathy LiDAR (Question 20)

Question 20. For the Mission Critical Activity that you specified, please describe the importance of seamless integration of your topographic LiDAR, bathymetric LiDAR, and/or topobathymetric LiDAR datasets if acquired on different dates or with different sensors.		
Answer Options	**Response Percent**	**Response Count**
Required	19.6%	19
Highly desirable	35.1%	34
Nice to have	27.8%	27
Not required	16.5%	16
No response	1.0%	1
	Total	**97**

Table 22. Types of data integration

Question 21. For the Mission Critical Activity that you specified, please describe the importance of integration of your LiDAR datasets with the data types listed below. For each data type, identify how important the data integration is to your program. Examples of data integration would be data you require for geospatial analysis or data you need for visual inspection. Please also describe the type of integration you require: spatial, temporal, or both. An example of spatial integration would be data from two different datasets that are seamless. An example of temporal integration would be data that were collected at the same time or within the same flying season.

Importance

Answer Options	Required	Highly Desirable	Nice to Have	Not Required	No Response	Response Count
Shorelines: current, historic, or change rates	29	22	21	15	10	97
Land Use/Land Cover	23	32	19	15	8	97
Estuaries/Wetlands/ Mangroves	20	40	20	10	7	97
Hydrography	30	37	12	8	10	97
Bridges and Culverts	18	28	24	17	10	97
Other	8	2	0	0	1	11

Type of Integration

Answer Options	Spatial	Temporal	Both Sp. & Temporal	None	No Response	Response Count
Shorelines: current, historic, or change rates	20	4	43	17	13	97
Land Use/Land Cover	20	6	46	14	11	97
Estuaries/Wetlands/ Mangroves	28	5	45	9	10	97
Hydrography	27	3	46	8	13	97
Bridges and Culverts	26	4	34	16	17	97
Other (please specify)	3	2	5	1	2	13

Table 23. Importance of benefits from currently available LiDAR data (Question 22)

Question 22. What benefits relative to your program budget are you now realizing from currently available LiDAR data? Check the box that most closely describes the benefits for each benefit type.

Answer Options	Major	Moderate	Minor	None	Don't know	No Response	Response Count
Time or cost savings (operational benefits)	46	17	7	12	11	4	97
Mission compliance (operational benefits)	38	32	11	8	4	4	97
Products or services (customer service benefits)	41	28	9	12	3	4	97

Question 22. What benefits relative to your program budget are you now realizing from currently available LiDAR data? Check the box that most closely describes the benefits for each benefit type.						
Answer Options	**Major**	**Moderate**	**Minor**	**None**	**Don't know**	**No Response**	**Response Count**
Response or timeliness (customer service benefits)	31	26	13	17	6	4	97
Customer experience (customer service benefits)	27	25	18	15	8	4	97
Education or public safety (societal benefits)	27	27	16	13	10	4	97
Environmental benefits (societal benefits)	28	32	15	9	9	4	97
Human lives saved (societal benefits)	15	11	18	18	31	4	97
Other (please specify)	0	0	0	0	0	0	2

Table 24. Importance of benefits from improved LiDAR data (Question 24)

Question 24. What benefits relative to your program budget would you likely receive from improved LiDAR data if all of your requirements could be met for the selected Mission Critical Activity? Check the box that most closely describes the benefits for each benefit type.							
Answer Options	**Major**	**Moderate**	**Minor**	**None**	**Don't know**	**No Response**	**Response Count**
Time or cost savings (operational benefits)	50	17	5	8	13	4	97
Improved mission compliance (operational benefits)	52	26	6	3	6	4	97
Improved products or services (customer service benefits)	54	21	8	5	5	4	97
Improved response or timeliness (customer service benefits)	37	25	7	13	11	4	97
Improved customer experience (customer service benefits)	38	19	12	11	13	4	97
Improved education or public safety (societal benefit)	39	21	12	10	11	4	97
Environmental benefits (societal benefits)	37	35	6	5	10	4	97
Human lives saved (societal benefits)	18	14	11	19	31	4	97
Other (please specify)	0	0	0	0	0	0	2

Table 25. Relative importance of geography, accuracy, point density, update frequency (Question 27)

Question 27. Which of these aspects of your data requirements is the most important? Please rank the options from most important (1) to least important (4).

Answer Options	1	2	3	4	No Response	Response Count
Geographic coverage	41	18	18	11	9	97
Vertical accuracy	38	37	8	5	9	97
Point density	4	22	33	29	9	97
Update frequency	5	11	29	43	9	97

Summary of Annual Dollar Benefits from Current and Future LiDAR Datasets

Tables 26 and 27 summarize annual dollar benefits from Florida's current and future (improved) topographic and bathymetric LiDAR datasets.

Table 26. Total Annual Dollar Benefits from Current and Future LiDAR Datasets (Questions 23, 26)

Current and Future Additional Benefits from LiDAR[1]	Annual Benefits
Currently available topographic LiDAR – minimum annual benefits	$44,980,000/year
Currently available topographic LiDAR – maximum annual benefits	$49,060,000/year
Future additional topographic LiDAR – minimum annual benefits	$31,377,000/year
Future additional topographic LiDAR – maximum annual benefits	$43,732,833/year
Future bathymetric/topobathymetric LiDAR – minimum annual benefits	$65,780,500/year
Future bathymetric/topobathymetric LiDAR – maximum annual benefits	$71,914,667/year

Table 27. Additional annual dollar benefits from improved LiDAR data, by Primary Business Use

Business Uses w/ Annual Dollar Benefits (Primary Business Use Only)	Topographic LiDAR Benefit		Bathymetric LiDAR Benefit	
	Min/Year	Max/Year	Min/Year	Max/Year
BU 1 – Natural Resources Conservation	$1,952,500	$2,525,000	$847,500	$1,125,000
BU 2 – Water Supply and Quality	$5,880,000	$10,955,000	$320,000	$595,000
BU 3 – River and Coastal Ecosystem Mgt.	$832,000	$1,082,000	$18,000	$18,000
BU 4 – Coastal Zone Management	$235,000	$445,000	$265,000	$555,000
BU 5 – Forest Resources Management	$575,000	$705,000	$45,000	$55,000
BU 7 – Wildlife and Habitat Management	$230,000	$350,000	$120,000	$200,000
BU 10 – Geologic Resource Assessment	$1,300,000	$1,325,000	$50,000	$75,000
BU 13 – Oil and Gas Resources	$375,000	$750,000	$125,000	$250,000
BU 14 – Cultural Resources Preservation	$270,000	$360,000	$30,000	$40,000

[1] These annual dollar benefits assume that each Mission Critical Area receives the LiDAR Quality Level and Update Frequency specified. For implementation scenarios that evaluate poorer Quality Levels and Update Frequencies, these annual benefits will be degraded by factors explained in Tasks 4 and 5 below. No dollar benefits were estimated for 33 of 97 MCAs, even when operational and/or customer service benefits were "major."

Business Uses w/ Annual Dollar Benefits (Primary Business Use Only)	Topographic LiDAR Benefit		Bathymetric LiDAR Benefit	
	Min/Year	Max/Year	Min/Year	Max/Year
BU 15 – Flood Risk Management	$5,962,500	$7,897,500	$1,137,500	$1,252,500
BU 16 – Sea Level Rise & Subsidence	$1,100,000	$1,100,000	$1,000,000	$1,000,000
BU 17 – Wildfire Management/Response	$180,000	$270,000	$20,000	$30,000
BU 20 – Marine Navigation and Safety[2]	$9,300,000	$10,300,000	$60,287,500	$64,287,500
BU 22 – Infrastructure/Construction Mgt.	$2,150,000	$4,533,333	$800,000	$1,716,667
BU 23 – Urban & Regional Planning	$525,000	$625,000	$125,000	$125,000
BU 26 – Education, Basic Research	$10,000	$10,000	$90,000	$90,000
BU 30 – Maritime & Land Boundary Mgt.	$500,000	$500,000	$500,000	$500,000
Totals	**$31,377,000**	**$43,732,833**	**$65,780.500**	**$71,914,667**

Estimation of Costs

In the Cost-Benefit Analysis, Dewberry used the best available data to estimate costs per square mile for acquisition and delivery of topographic and bathymetric/topobathymetric LiDAR for 500 square mile or larger Areas of Interest (AOIs) by Quality Level, recognizing that topographic LiDAR costs are higher in Florida than elsewhere in the U.S. because of the large number of hydrographic features in Florida requiring breaklines. Actual costs can vary greatly, depending on local circumstances. However, because such costs are confidential, only approximate cost difference percentages are shown Table 28, using the better-understood QL2 topographic LiDAR and QL0B bathymetric LiDAR as the points of reference. Note that QL0B and QL2B costs are similar (less than 2% difference, flown at the same flying height), QL1B and QL3B costs are similar (flown at the same flying height) and QL4B is the least expensive. For the bathymetric Quality Level pairs that are similar, the more expensive Quality Level has additional control points for submerged points, and tighter LiDAR calibration procedures. In the case of bathymetric LiDAR, QL2B costs more than QL1B, contrary to normal convention, because QL2B point density is so much higher than QL1B, but this remains debatable in the eyes of USACE and NOAA.

Table 28. LiDAR Quality Level Relative Cost Differences

Topo LiDAR Quality Level Cost Comparisons		Bathy LiDAR Quality Level Cost Comparisons
QL1 is ~1.4 times more expensive than QL2		QL0B is <2% more expensive than QL2B
QL0 is ~1.6 times more expensive than QL2		QL0B is ~18% more expensive than QL1B
		QL0B is ~20% more expensive than QL3B
		QL0B is ~42% more expensive than QL4B

These cost estimates pertain only to standard LiDAR deliverables for the 3DEP and 3D Nation. They do not include Florida's additional costs for management and QC, costs for storage and dissemination, or costs for "buy-up" options such as Digital Surface Models (DSMs), hydro-enforced Digital Terrain Models (DTMs), 2-D or 3-D footprints, power lines, and other forms of breaklines. Costs of hydro-

[2] Whereas it may appear illogical for BU 20 to accrue the highest dollar benefits from topographic LiDAR, this happened because benefits accrue to the primary BU indicated for each MCA. Several MCAs with the highest dollar benefits required both topographic and bathymetric LiDAR; and when major benefits for an MCA are split between BU 20 (primary) and other BUs identified as secondary or tertiary, and the benefit split is perhaps 25% topo to 75% bathy, a significant benefit accrues to topographic LiDAR even though the primary BU is for marine navigation and safety. Related secondary BUs of 1, 2, 3, 4, 16 or 17, for example, would accrue no benefits.

enforcement varies greatly, depending on how culverts are identified and "cut" into the DTMs, as well as the variable size of lakes and ponds and the width of dual-line or single-line streams to be enforced.

Task 3: Assessment and Review of Emerging Data Collection Technologies

Evaluation of Technology Trends

This section compares the capabilities and limitations of elevation data collected using competing LiDAR sensors, and the projected timing of when new technologies are expected to be mature for use.

Topographic LiDAR System Trends

Over the past several years, topographic LiDAR systems have seen improvement in the efficiency of acquisition as well as the introduction of new types of topographic LiDAR systems into the market. The improvements to traditional LiDAR systems and the availability of Geiger Mode and photon counting systems have led to an increase in point density and the ability to collect data at a higher altitude and/or faster flight speeds. Traditional (or linear) LiDAR systems have improved their collection efficiencies through the use of multiple lasers in the same sensor or through splitting a single laser into multiple beams. At the same time, improvements in the laser power and reduced beam divergence allow these sensors to operate at higher altitudes while maintaining the same laser spot size on the ground. The result of these improvements to traditional systems is significantly improved acquisition times. Figure 3 shows an example of an older sensor (Riegl LMS Q680i) flight plan against a newer sensor (Riegl LMS Q1560) flight plan. Each plan has the same point density (2 points per square meter) and accuracy requirement. As shown in Figure 3, the newer Q1560 sensor requires far fewer (blue) flight lines to cover the same area as the older sensor (red flight lines).

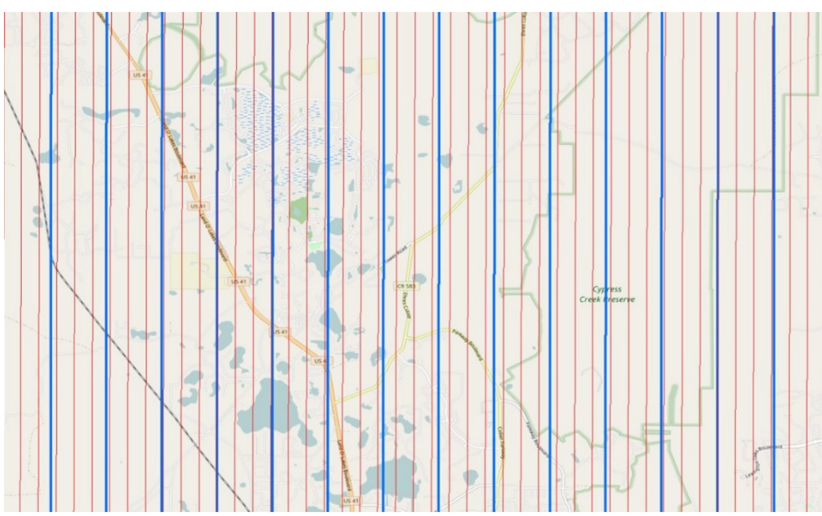

Figure 3. Fewer flight lines (blue) with new Q1560 sensor than older Q680i sensor (red flight lines)

As traditional LiDAR sensors have improved, new technologies have also come to market that extend the capabilities of topographic LiDAR. These technologies include Geiger mode and photon counting LiDAR systems. Both of these systems continue to have a limited number of vendors supplying the data and commercial software support for processing these data is limited. The software needed to convert the raw photon data acquired by the sensor to a point cloud data in LAS format is limited to the system manufacturer's proprietary software, which is currently not available to data providers. This is likely to change over the next few years as more commercial systems become available for purchase by LiDAR acquisition providers. The single photon system that is commercially available (Leica SPL100) also has the potential to extend the traditional topographic collections into the topobathymetric range, as it uses a green wavelength laser which is capable of penetrating through water in very shallow environments. The potential benefit of this type of sensor is that it may ultimately reduce the cost of coastal topobathymetric surveys if they can be done from a much higher altitude than the current sensors allow.

A recent study conducted by the U.S Geological Survey evaluated the commercially available Gieger mode LiDAR sensor and Single Photon sensor to determine if they would acquire data that met the 3D Elevation Program's requirements (Stoker et al., 2016 – available online at: http://www.mdpi.com/2072-4292/8/9/767/htm). The study noted that while these sensors were not able to collect data currently to meet USGS LiDAR base specification, this was partially due to the fact that the specification was written for linear-mode systems specifically. With little effort on part of the manufacturers of the new LiDAR systems and the USGS LiDAR specifications team, data from these systems could soon serve the 3DEP program and its users. Many of the shortcomings noted in the study have been reported to have been corrected or improved upon in the next generation sensors.

Topographic LiDAR systems still face some challenges when acquiring LiDAR data in Florida because of the dense vegetation and no true leaf-off conditions. The latest systems are more capable of returning pulses that represent ground under foliage since they can send out millions of pulses per second and are able to receive more returns per pulse. They also tend to have more sensitive detectors incorporated into the system. A recent LiDAR survey conducted by Dewberry in Hillsborough County, FL, using the new Riegl VQ1560i sensor acquired over 24 points per square meter and resulted in a dense data set that produced bare earth elevations under dense foliage including mangroves. The high point density and sufficient swath overlap ensured that the laser pulses penetrated through gaps in the canopy from many different directions, thereby increasing the probability of some of those laser pulses reaching the ground. Foliage penetration is a big concern and surveys should be planned for based on the specific area of interest and the types of vegetation and conditions for that area.

Bathymetric LiDAR System Trends

Systems designed to acquire bathymetric LiDAR have been subject to many improvements over the last few years. These systems have been improved to collect higher densities of points in shallow water. Additionally, multiple systems coming to market incorporate additional lasers to either collect deeper water bathymetry or additional topographic LiDAR during the same flights. A recent survey conducted by Dewberry in Everglades National Park, FL, combined a topographic LiDAR sensor (Riegl VQ680i) with a topobathymetric LiDAR sensor (Riegl VQ820G) to acquire Quality Level 1 data. The topographic and topobathymetric LiDAR sensors were selected to penetrate through the dense canopy as well as penetrate through the shallow bathymetry found in sloughs and wetland habitats. In addition to the improvements in the hardware, there have also been significant gains in the software for bathymetric

LiDAR processing that enable users to more quickly process the data. All of the improvements have led to a decrease in the amount of time required to collect the LiDAR data when weather and water conditions meet the collection requirements.

The primary challenges when acquiring bathymetric LiDAR continue to be issues such as white water and water clarity in general. Additionally, the flying heights for these newer sensors is still much lower than that of a topographic LiDAR sensor. This results in a much higher cost for collection of bathymetric LiDAR when compared to topographic LiDAR, as not as much area can be covered in a single pass. In Florida, these sensors have the potential to collect data where the water is relatively clear such as along the coasts, in areas of springs, and in some shallow wetlands. The challenges faced by these sensors are mostly related to inland waterways where the water is brackish or has high levels of turbidity, which is also the case with most inland rivers, lakes, and ponds in Florida.

Evaluation of Coastal Zone Considerations

The National Science and Technology Council has developed the National Coastal Mapping Strategy 1.0: *Coastal LiDAR Elevation for a 3D Nation*, in which it proposes bathymetric LiDAR Quality Levels ($QL0_B$, $QL1_B$, $QL2_B$, $QL3_B$ and $QL4_B$) equivalent to topographic LiDAR Quality Levels in the USGS Lidar Base Specification (QL0, QL1, and QL2). All Quality Levels were explained in answers to Frequently Asked Questions (FAQs) linked to specific questions in the questionnaire.

For this study, Dewberry assumed the most modern sensors would be used, as it has acquired and processed topobathymetric LiDAR data for NOAA and USGS using all major topobathymetric LiDAR sensors, including: Leica – AHAB Chiroptera II, Leica – AHAB Hawkeye, Optech CZMIL, Optech SHOALS, Optech Titan, NASA/USGS EAARL, Riegl VQ820G, and Riegl VQ880G. For all bathymetric scenarios, Dewberry assessed all existing and emerging bathymetric and topobathymetric LiDAR sensors for Florida's coastal zone applications to include ports, nearshore environments, national estuarine research reserves, marine sanctuaries, and wetland ecosystems.

Florida's coastal zone represents a major economic concern within the State. Florida's beaches define the "state brand," according to a January 2015 study by Florida's Office of Economic and Demographic Research: "Economic Evaluation of Florida's Investment in Beaches." This study shows that "The state's investment in the Beach Management and Restoration Program generated a positive return on investment of 5.4. … The state invested $44 million in the Beach and Management Restoration Program during the review period resulting in an average increase in GDP of $2.4 billion per year. This, in turn, increased the overall collection of state revenues by $237.9 million over the three year period." Additionally, almost half of Florida's 825 miles of shoreline is critically eroding, according to the Florida DEM study in 2010. Understanding that these areas are critically important to the revenue base in Florida, this section looks at how LiDAR can be used to aid the state in its decision-making processes related to the coastal zone.

In areas around the coast where the water is clear, bathymetric or topobathymetric sensors will be able to collect data to aid in the management of the coastal zone. Ports represent a greater challenge for these types of technologies as the deep water and often turbid conditions do not lend themselves to successful LiDAR collections. In these instances, multi-beam or single beam acoustic surveys would likely yield a much better result where collection of the submerged topography is desired.

For the beaches and nearshore area, topobathymetric or bathymetric sensors would be capable (given the right conditions) of collecting the submerged topography and onshore topography. There have been many instances of successful collects in the last few years in Florida including collections in the Florida Keys and along the coast using topobathymetric sensors. When collected at higher densities, these data are capable of aiding with the management of estuarine and marine sanctuaries as small details related to the submerged topography can be extracted from the data. This includes areas where motorized watercraft cause damage to the subaquatic vegetation. Additionally, the coastal area could be quickly collected using a topographic LiDAR sensor while the water elevations are near mean lower low tide to measure the elevations and width of beaches. When collected over multiple temporal periods, this would allow the state of Florida to manage beach erosion and determine where beaches may need to be extended or repaired to help mitigate storm surge related flooding. A similar project was done using a helicopter along the U.S. west coast by Dewberry for NOAA, USGS, and the USACE to measure the effects of El Nino on the beaches of the west coast. In addition to standard topographic LiDAR sensors, it may be beneficial to assess the cost effectiveness of unmanned aerial systems (UAS) or small unmanned aerial system (sUAS) LiDAR collections in areas where conditions warrant more frequent evaluation of the change.

Depending on the specific project area, one or more of the currently available commercial sensors would likely be able to provide a solution to the acquisition of bathymetric data along coastal zones in Florida. Emerging technologies such as the SPL100 single photon LiDAR system may have the ability to increase the collection efficiency and provide some extension into more turbid waters, but would need to be tested to determine its capabilities and the optimal conditions for the use of that sensor.

Identification of Key Risks

What we commonly call “elevations” in Digital Elevation Models (DEMs) are technically *orthometric heights* (H) above the geoid, an undulating equipotential surface that models mean sea level beneath the terrain and varies with local changes in gravity. Orthometric heights follow the rules of gravity. However, elevation data from GPS (either ground-based or airborne GPS used for LiDAR data acquisition) are *ellipsoid heights* (h) above a smooth mathematical surface called the ellipsoid. Ellipsoid heights follow the rules of geometry. The difference between these two heights is called the *geoid undulation*. See Figure 4.

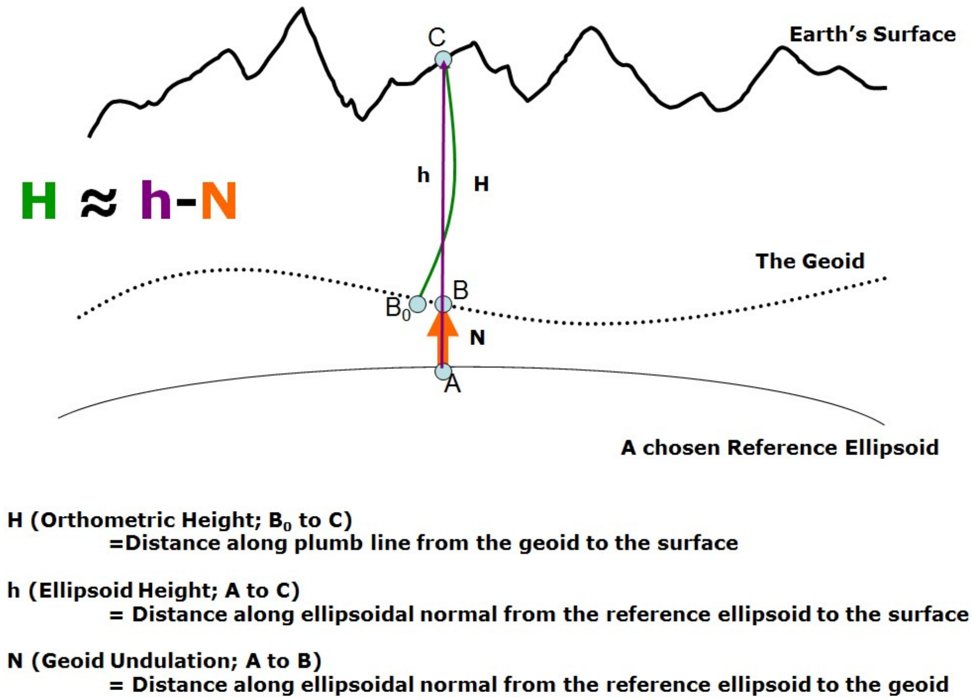

Figure 4. Orthometric Heights, Ellipsoid Heights, and Geoid Undulations

Geodetic leveling, supporting the computation of approximate orthometric heights at passive geodetic control marks was the way that vertical datums have been defined and accessed for centuries; but many passive geodetic control marks and benchmarks in Florida have subsided, and their elevations change, often without the knowledge of those who rely upon such monuments to establish vertical survey control. The advent of GPS, especially its speed and accuracy as a surveying tool, as well as the improved accuracy of geoid undulation models has driven an intense scrutiny of a new approach toward vertical datums in the last ten years. In some parts of the world this scrutiny has yielded a radical shift in vertical datum approach and soon (2022) the United States will follow suit.

Beginning in 2022, all vertical datums of the civilian federal government, as defined by the National Geodetic Survey, will be "geoid based vertical datums." This means that the vertical datums will all work in orthometric heights and will be accessed through GPS receivers. For this to work accurately, a geoid undulation model of unprecedented accuracy must be built. For this purpose, NGS has engaged in the GRAV-D (Gravity for the Redefinition of the American Vertical Datum) project. The GRAV-D project is an airborne gravity survey campaign running from 2007 until 2021, as well as the establishment of a geoid monitoring service (to introduce continental scale time dependencies in the gravity field). Once GRAV-D is complete, a new geoid undulation model will be computed for North America (including all of Alaska, Greenland, Canada, conterminous U.S. [CONUS], Mexico, Central America, the Caribbean and Hawaii) which will serve as the new "zero elevation surface" for the geoid based vertical datum.

Florida needs to prepare now for what happens in 2022 when virtually every latitude, longitude and elevation value in the U.S. will change. Fortunately, the changes in Florida will be the least anywhere in the U.S.

The following are three Florida-specific risks that can be mitigated by recommended actions:

- Florida can specify, now, that it wants all future LiDAR datasets to be delivered as both orthometric heights and ellipsoid heights. Then when the new geoid undulation model is released in 2022, it will be simpler to recompute orthometric heights for the new North American-Pacific Geopotential Datum of 2022 (NAPGD2022).
- Passive survey monuments (benchmarks) have long been subject to subsidence in Florida. Passive benchmarks have been used statewide with elevation errors of 1' to 2' or more compared with their published elevations on NGS datasheets. Passive monuments should not be used for base stations, survey control or QA/QC checkpoints unless they have been recently GPS-surveyed relative to the nearest CORS stations and processed via NGS' Online Positioning User Service (OPUS) to validate their current ellipsoid heights and orthometric heights.
- Dewberry was once hired by a Florida County to determine why two different firms had delivered adjoining LiDAR datasets of flat terrain, both tested to 1' contour accuracy, but the seamline between the two LiDAR datasets was 2' tall. How could this be? An investigation determined that one of the firms had incorrectly used local benchmarks, not tied to CORS, as GPS base stations for the LiDAR acquisition and also used by another firm that performed independent QA/QC. When both firms used the same inaccurate base stations, the errors cancelled out and the data appeared to pass the requirement for 1' contour accuracy (4" RMSEz). Florida communities must insist that all GPS base stations be tied to CORS stations.

Task 4: Development and Assessment of Program Implementation Scenarios

Dewberry performed Cost-Benefit Analysis on five Program Implementation Scenarios. Task 4 of this report addresses scenario changes in LiDAR Quality Levels, and Task 5 of this report addresses scenario changes in LiDAR Update Frequencies.:

- Scenario 1: Florida Statewide Topographic LiDAR
- Scenario 1a: County-by-County Topographic LiDAR
- Scenario 2: Florida Statewide Topobathymetric LiDAR (Coastal Nearshore Bathy Only)
- Scenario 2a: County-by-County Topobathymetric LiDAR (Coastal Nearshore Bathy Only)
- Scenario 3: Florida Statewide Topobathymetric LiDAR (Inland Bathy + Nearshore Bathy)

Dewberry's Geospatial Financial Model

Dewberry's Geospatial Financial Model was developed to identify both the optimum Quality Level and optimum Update Frequency that will yield the highest Net Benefits for topographic LiDAR and bathymetric LiDAR, whether that model is applied statewide or to individual counties. Dewberry does this by comparing Quality Level and Update Frequency requirements for each MCA with 15 potential implementation scenarios for topographic LiDAR (3 potential topographic LiDAR Quality Levels x 5 potential Update Frequencies) and 25 potential implementation scenarios for bathymetric LiDAR (5 potential bathymetric LiDAR Quality Levels x 5 potential Update Frequencies) to compute the consolidated Net Benefits for each scenario for all (97) MCAs combined. This Financial Model is based on Quality Level multipliers discussed here in Task 4 and Update Frequency multipliers discussed in Task 5, below.

Quality Level Multipliers

For topographic LiDAR, Table 11 shows that for 97 MCAs, 42 required QL2 LiDAR, 36 required QL1 LiDAR, 17 required QL0 LiDAR, and two added comments that they required different Quality Levels for different areas in order to achieve annual benefits between $31.377M and $43.733M – but only if they received the topographic LiDAR Quality Level and Update Frequency equal to or better than specified by LiDAR users/stakeholders for each MCA.

Similarly for topobathymetric LiDAR, Table 19 indicates that for 97 MCAs, 26 required QL2B, 13 required QL0B, 12 required QL1B, 7 required QL3B, and 6 required QL4B in order to achieve annual benefits between $65.733M and $71.915M – but only if they received the topobathymetric LiDAR Quality Level and Update Frequency equal to or better than that specified for each MCA. The remaining 33 required topographic LiDAR only.

However, when considering three topographic LiDAR Quality Levels and five topobathymetric LiDAR Quality Levels to determine the highest benefits, Dewberry uses **Quality Level reduced value multipliers** for any scenario in which an individual MCA receives data of poorer quality than specified. (In Task 5, Dewberry does the same thing for any scenario in which an individual MCA receives data or poorer Update Frequency than specified.) Dewberry did this for the original NEEA study and modified this tried-and-proven technique for the Florida Statewide LiDAR Assessment where the Quality Level differences were smaller than those used in the NEEA study. Dewberry then performed sensitivity analyses to determine if conclusions would change significantly if different multipliers are used.

For the NEEA study, a uniform Quality Level multiplier of 0.5 was used between each of five Quality Levels that were extremely different – between different technologies (LiDAR, photogrammetry and IFSAR), and where accuracies varied between 1’ and 20’ contour accuracies and where point density varied between 8 points per square meter and 1 point every 5 meters. For Florida, the three topographic LiDAR Quality Levels and five bathymetric LiDAR Quality Levels were relatively similar. If Florida used a 0.5 Quality Level multiplier between all Quality Levels, the highest quality level would always win and this would not be considered a credible assessment.

Table 29 demonstrates how a uniform Quality Level multiplier of 0.8 would work for an MCA that would receive $100,000 in annual benefits for any scenario that delivers a Quality Level equal to or better than specified, but reduced benefits for any scenario that delivers a Quality Level poorer than specified. A multiplier of 0.8 is roughly equivalent to the difference in costs between QL0 and QL1. The 0.8 multiplier was the first of many alternatives that Dewberry considered for both topographic and bathymetric LiDAR because it approximated cost differences between Quality Levels.

Table 29. How a 0.8 Quality Level Multiplier Works

Quality Level required for \$100,000 annual benefits	QL0 scenario annual benefits received	QL1 scenario annual benefits received	QL2 scenario annual benefits received
QL0	\$100,000	\$80,000	\$64,000
QL1	\$100,000	\$100,000	\$80,000
QL2	\$100,000	\$100,000	\$100,000

The defining issue for the Florida assessment was how to degrade Quality Levels that were relatively similar. This issue will be addressed separately for topographic and topobathymetric LiDAR below.

Scenario 1: Statewide Topographic LiDAR Quality Level

Table 1 shows the differences between topographic LiDAR Quality Levels, and Table 28 shows their relative differences in costs. The main advantage of QL1 over QL2 is the high point density for QL1 (8 pts/m^2) compared to the nationwide standard point density for QL2 (2 pts/m^2). This higher point density is especially relevant in those portions of Florida where vegetation is very dense and difficult to penetrate with fewer points per square meter. The main advantage of QL0 over QL1 is the better vertical accuracy (RMSEz of 5 cm for QL0 vs. 10 cm for QL1) which is equivalent to the difference between 6" and 1' contour accuracy; QL0 has the same high point density as QL1 (8 pts/m^2) and therefore does not provide any better vegetation penetration than QL1.

After performing many forms of Quality Level sensitivity analyses, Dewberry decided on a hybrid Quality Level multiplier based on the following:

- Between QL0 and QL1, where differences are minor, the Quality Level degradation factor will be 0.86587, the relative cost ratio between these two Quality Levels.
- Between QL1 and QL2, where differences are larger, the Quality Level degradation factor will be 0.5, equal to the degradation factor used in the NEEA. This enables Florida's assessment to be compatible with USGS' nationwide LiDAR assessment (which did not include QL0).

Table 30 demonstrates how Dewberry's hybrid Quality Level multipliers work for an MCA that would receive \$100,000 in annual benefits for any scenario that delivers a Quality Level equal to or better than specified, but reduced benefits for any scenario that delivers a Quality Level poorer than specified.

Table 30. How Dewberry's Hybrid Quality Level Multiplier Works

Quality Level required for \$100,000 annual benefits	QL0 scenario annual benefits received	QL1 scenario annual benefits received	QL2 scenario annual benefits received
QL0	\$100,000	\$86,587	\$43,293
QL1	\$100,000	\$100,000	\$50,000
QL2	\$100,000	\$100,000	\$100,000

Scenario 1 Conclusion: Tables in Task 5 will show how this Cost-Benefit Analysis ultimately concludes that QL1 topographic LiDAR is the best alternative statewide when considering both Net Benefits and Benefit/Cost Ratios.

Scenario 1a: County-by-County Topographic LiDAR Quality Level

Dewberry evaluated each county individually, and the results changed significantly – depending on high value benefits for individual MCAs provided by some counties, regional planning councils, and water management districts, compared with others. This will be explained further in Task 5.

Scenario 2: Statewide Topobathymetric LiDAR Quality Level, Nearshore Bathy Only

Accompanied by Figure 5, Question 9 asked where LiDAR data are needed; the pick-list of answers included:

- inland topography
- inland bathymetry
- beaches and dunes
- littoral zone
- nearshore bathymetry
- offshore bathymetry

Question 9 was also accompanied by a FAQ that addressed the limitations of topobathymetric LiDAR for inland bathymetry.

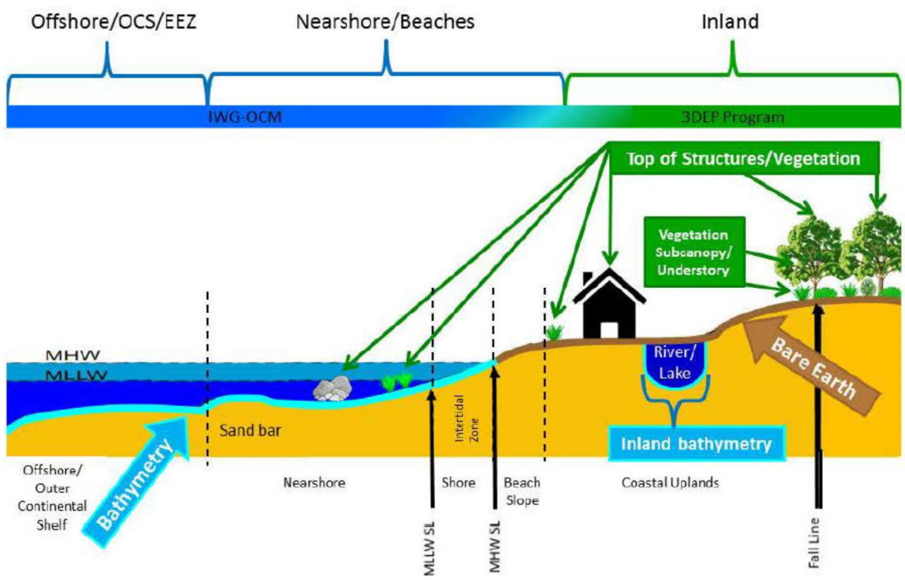

Figure 5. Question 9 was accompanied by this graphic and assumed respondents read FAQ #5 and understood the limitations of bathymetric LiDAR for inland bathymetry.

Scenario 2 addresses only nearshore bathymetry, out to the 10m depth contour (20' depth contour in south Florida where waters are clearer), where topobathymetric LiDAR is expected to be effective. The SurveyMonkey® questionnaire was accompanied by answers to Frequently Asked Questions (FAQs) for which FAQ #5 addressed the differences between topographic, bathymetric and topobathymetric LiDAR and their advantages and limitations. A limitation of topobathymetric LIDAR was stated as follows in bold print: "**Depending on the technology used and time of survey, topobathymetric LiDAR may be expected to work in several of Florida's clear springs, some wetland environments, and in shallow Florida bays when waters are clear, but it is not expected to perform very well in Florida's larger rivers, intracoastal waterways and lakes that are turbid. A mix of topobathymetric LiDAR and acoustic (multibeam sonar) surveys would be required for most bathymetric areas in Florida.**"

Nearshore bathymetry, shown in blue at Figure 6, comprises only 20.2% of the state when adding blue areas to the beige areas; therefore, for MCAs that indicated requirements for and benefits from both inland bathymetry and nearshore bathymetry, only 20.2% of those bathymetric benefits were counted for Scenario 2 as there would be no benefits for inland bathymetry from Scenario 2. Furthermore, if an MCA indicated requirements for inland bathymetry only, then no benefits were counted for Scenario 2 which pertains only to nearshore bathymetry.

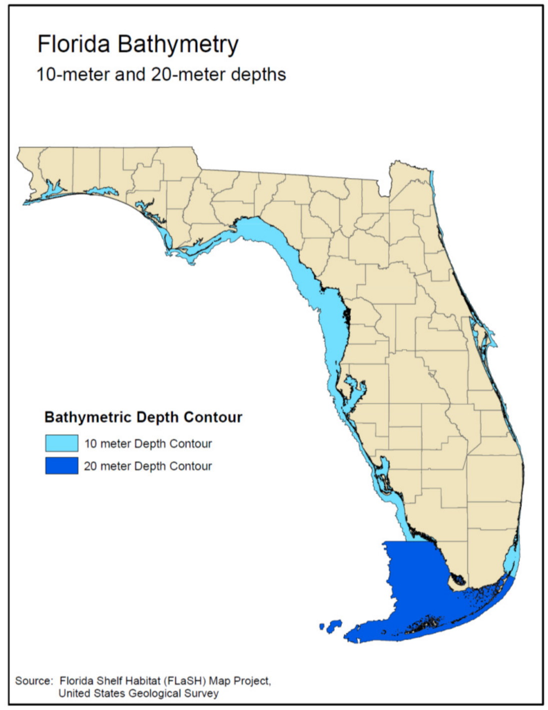

Figure 6. Scenario 2 Area of Interest (blue) for topo-bathymetric LiDAR of nearshore bathymetry only.

Bathymetric/topobathymetric LiDAR is more complicated to analyze than topographic LiDAR. Table 31 provides three different options for comparing bathymetric Quality Levels:

1. Reduced value multipliers could be applied between each of the five topobathymetric LiDAR Quality Levels shown in Table 31, i.e., between QL0B, QL1B, QL2B, QL3B and QL4B. Here the results are straight forward.
2. Reduced value multipliers could be applied between the three different applications, i.e., between bathymetric datasets suitable for detailed site surveys (QL0B and QL1B), charting surveys (QL2B and QL3B), and reconnaissance/planning (QL4B). But costs are very different between Quality Levels for the same application, and results are confusing.
3. Reduced value multipliers could be applied between products in three distinctly different cost categories shown in different colors in Table 31, i.e., the highest density and highest cost Quality Levels in red (QL0B and QL2B), the mid-density and mid-cost Quality Levels in green (QL1B and QL3B), and the lowest density, lowest cost Quality Level in blue (QL4B). But results are confusing because both QL0B and QL2B cost more than QL1B.

Table 31. Topobathymetric LiDAR Quality Level Comparisons

	QL0B	QL1B	QL2B	QL3B	QL4B
Aggregate Nominal Pulse Spacing	≤0.7 m	≤2.0 m	≤0.7 m	≤2.0 m	≤5.0 m
Aggregate Nominal Pulse Density	≥2.0 pts/m^2	≥0.25 pts/m^2	≥2.0 pts/m^2	≥0.25 pts/m^2	≥0.04 pts/m^2
Depth Examples	Vertical Accuracy of submerged elevations at 95% Confidence Level (cm)				
0 m	25.0	25.0	30.0	30.0	50.0
10 m	26.1	26.1	32.7	32.7	51.7
20 m	29.2	29.2	39.7	39.7	56.4
Applications	Detailed site surveys requiring the highest accuracy and highest resolution seafloor definition; dredging and inshore engineering surveys; high-resolution surveys of ports and harbors		Charting surveys; regional sediment management; general bathymetric mapping; coastal science and management applications; change analysis; deep water surveys; environmental analyses		Recon/planning; all general applications not requiring higher resolution and accuracy
Estimated Cost/Sq Mi	Base Cost	~18% cheaper than QL0B	<2% cheaper than QL0B	~20% cheaper than QL0B	~42% cheaper than QL0B

Dewberry evaluated two forms of Quality Level reduced value multipliers for bathymetric LiDAR: (1) one used a uniform 0.8 Quality Level multiplier between bathymetric LiDAR Quality Levels when ranked in the order of their cost per square mile, and (2) the other used actual cost difference multipliers based on estimated costs for each bathymetric LiDAR Quality Level listed in Table 31.

Table 32 shows how the bathymetric LiDAR cost difference multipliers work. Note that QL1 and QL2 are re-ordered in Table 32 to account for QL2B costing more than QL1B, but less than QL0B.

Table 32. Topobathymetric LiDAR Cost Difference Multipliers

Quality Level Required	But QL0B Received	But QL2B Received	But QL1B Received	But QL3B Received	But QL4B Received
QL0B	1.0	0.9894	0.8507	0.7155	0.4972
QL2B	1.0	1.0	0.8598	0.8411	0.6948
QL1B	1.0	1.0	1.0	0.9783	0.8261
QL3B	1.0	1.0	1.0	1.0	0.8444
QL4B	1.0	1.0	1.0	1.0	1.0

Scenario 2 Conclusion: Tables in Task 5 will show how a cost-benefit analysis ultimately concludes that either QL2B or QL0B topobathymetric LiDAR are the best alternatives statewide when considering both Net Benefits and Benefit/Cost Ratios.

Scenario 2a: County-by-County Topobathymetric LiDAR Quality Level, Nearshore Bathy Only

Dewberry evaluated each county individually with a topobathymetric Quality Level multipliers and different update frequencies, and the results changed significantly – depending on high value benefits for individual MCAs provided by some counties and water management districts, compared with others.

Scenario 3: Statewide Topobathymetric LiDAR Quality Level, Inland + Nearshore

With Scenario 3, the highest Net Benefits are relatively poor when compared with Scenario 2. Although there are no technical reasons why topobathymetric LiDAR couldn't be collected over the entire state, the much higher annual costs (>$19M/year) result from having to fly a lot lower (400 m vs. 2,000 m) with a visible green wavelength laser, so flying at night over urban terrain could be problematic, even when assuming we could get clearance for low flights. Also, Florida would have little guarantee that it would successfully acquire additional bathymetry in rivers, lakes and ponds that are typically more turbid.

Task 5: Assessment of LiDAR Update Frequency Requirements

Dewberry's Geospatial Financial Model

In addition to Quality Level comparisons, Dewberry's Geospatial Financial Model also identifies the optimum Update Frequency that will yield the highest Net Benefits for topographic LiDAR and bathymetric LiDAR, whether that model is applied statewide or to individual counties. Dewberry does this by comparing Quality Level and Update Frequency requirements for each MCA with 15 potential implementation scenarios for topographic LiDAR (3 potential topographic LiDAR Quality Levels x 5 potential Update Frequencies) and 25 potential implementation scenarios for bathymetric LiDAR (5 potential bathymetric LiDAR Quality Levels x 5 potential Update Frequencies) to compute the consolidated Net Benefits for each scenario for all (97) MCAs combined. This Financial Model is based on Quality Level Multipliers discussed in Task 4, above, and Update Frequency Multipliers discussed here in Task 5.

Update Frequency Multipliers and Sensitivity Analyses

For both topographic LiDAR and bathymetric LiDAR, the Update Frequency options were: (a) annually, (b) 2-3 years, (c) 4-5 years, (d) 6-10 years, (e) >10 years, and (f) Event driven.

For topographic LiDAR, Table 12 shows that for 97 MCAs, 10 require annual updates, 26 require 2-3 year updates, 30 require 4-5 year updates, 15 require 6-10 year updates, two require >10-year updates, and 13 are event driven. One received no response to the Update Frequency question.

Similarly for topobathymetric LiDAR, Table 20 shows that for 97 MCAs, 5 require annual updates, 18 require 2-3 year updates, 18 require 4-5 year updates, 11 require 6-10 year updates, two require >10 year updates, and 12 are event driven. The remaining 31 have no requirement because they are applicable only to topographic LiDAR.

For any MCA where the Update Frequency selected was "Event driven," Dewberry used an Update Frequency multiplier of 0.5 because any cyclic data acquisition program could only provide the preevent elevation surface (e.g., surface before a hurricane) for comparison with a post-event elevation surface to provide change detection. Thus, only half of the two required datasets can be provided by any cyclic data acquisition program.

Identical to what Dewberry did for the NEEA study, Dewberry used an **Update Frequency reduced value multiplier of 0.5** between individual Update Frequency categories because this multiplier was also used for the NEEA for the same Update Frequency categories, and stakeholders agreed this was approximately correct. A sensitivity analysis for Florida, using different multipliers, also shows that 0.5 is approximately correct. Table 33 provides examples of how the 0.5 Update Frequency multiplier works, assuming each MCA would receive annual benefits of $100,000 if it received the Quality Level and Update Frequency of topographic LiDAR equal to or better than the Update Frequency required.

Table 33. How a 0.5 Update Frequency Multiplier Works

Update Frequency required for $100,000 annual benefits	Annual update scenario annual benefits received	2-3 year update scenario annual benefits received	4-5 year update scenario annual benefits received	6-10 year update scenario annual benefits received	>10 year update scenario annual benefits received
Annual	$100,000	$50,000	$25,000	$12,500	$6,250
2-3 years	$100,000	$100,000	$50,000	$25,000	$12,500
4-5 years	$100,000	$100,000	$100,000	$50,000	$25,000
6-10 years	$100,000	$100,000	$100,000	$100,000	$50,000
>10 years	$100,000	$100,000	$100,000	$100,000	$100,000
Event Driven	$50,000	$50,000	$50,000	$50,000	$50,000

Cost-Benefit Analysis Theory

Cost-Benefit Analysis theory is based on two maxims:

- In the absence of funding constraints, the “best value” for money projects are those with the highest Net Benefits (see red outlines in tables that follow).
- Where there is a budget constraint, the benefit/cost ratio (BCR) should be used.

This theory will be applied first on a statewide basis and then on a county-by-county basis.

Scenario 1: Statewide Topographic LiDAR

Table 34 shows topographic LiDAR metrics for our baseline update frequency multiplier of 0.5.

Table 34. Topographic LiDAR Metrics when using 0.5 Update Frequency Multiplier

Option #	Quality Level	Update Frequency	Annual Total Costs	Annual Total Benefits	Benefit/Cost Ratio (BCR)	Net Benefits (Benefits - Costs)
1	QL0	Annual	$22,984,477	$30,577,000	1.33	$7,592,523
2	**QL0**	**2-3 years**	$9,193,791	$30,190,750	3.28	**$20,996,959**
3	QL0	4-5 years	$5,107,662	$25,609,125	5.01	$20,501,463
4	QL0	6-10 years	$2,873,060	$18,609,563	**6.48**	$15,736,503
5	QL0	>10 years	$1,915,373	$9,709,781	5.07	$7,794,408
6	QL1	Annual	$19,901,485	$29,878,499	1.50	$9,977,014
7	**QL1**	**2-3 years**	$7,960,594	$29,523,938	3.71	**$21,563,344**
8	QL1	4-5 years	$4,422,552	$25,221,730	5.70	$20,799,178
9	QL1	6-10 years	$2,487,686	$18,415,865	**7.40**	$15,928,179
10	QL1	>10 years	$1,658,457	$9,612,933	5.80	$7,954,476
11	QL2	Annual	$14,220,375	$18,546,749	1.30	$4,326,374
12	QL2	2-3 years	$5,688,150	$18,356,969	3.23	$12,668,819
13	**QL2**	**4-5 years**	$3,160,083	$15,880,865	5.03	**$12,720,782**
14	QL2	6-10 years	$1,777,547	$11,172,933	**6.29**	$9,395,386
15	QL2	>10 years	$1,185,031	$5,960,216	5.03	$4,775,185

As shown with the red outlines, Table 34 shows QL1 LiDAR with Update Frequency of 2-3 years has the highest Net Benefits and is therefore the preferred alternative.

For Scenario 1, Dewberry concludes that QL1 topographic LiDAR, updated every 2-3 years, is the best alternative statewide when considering Net Benefits.

- ***Statewide Annual Costs: $7.96M (based on 2.5 years)***
- ***Statewide Annual Total Benefits: $29.52M (based on 2.5 years)***
- ***Statewide Annual Net Benefits: $21.56M (based on 2.5 years)***
- ***Benefit/Cost Ratio: 3.71***

Total cost for multi-year statewide acquisition: $19.90M.

If executed as a 3-year program, annual costs would be $6.63M

On a case-by-case basis, counties, Regional Planning Councils or Water Management Districts can "buy-up" to QL0 if they are able to pay for the higher costs.

Scenario 1a: County-by-County Topographic LiDAR

As shown at Figure 7, in a county-by-county assessment based on Net Benefits, only Leon County ($1.2M in additional annual benefits) and Pinellas County ($1M in additional annual benefits) would justify QL0 LiDAR with 2-3 year update frequency. Hillsborough and Martin counties (with smaller additional annual benefits) would justify QL0 with 4-5 year update frequency. Several other counties would warrant QL1 LiDAR with a 2-3 year update frequency. Whereas Figure 7 would appear to show that most counties would warrant QL1 LiDAR updated with 4-5 year update frequency, this is misleading because we did not have points of contact for most counties, so we did not know who to invite to participate in the questionnaire process.

Results vary greatly, therefore, because most counties and Regional Planning Councils were either not reached by our survey or they failed to provide requirements and dollar benefits that could be factored into a Cost-Benefit Analysis.

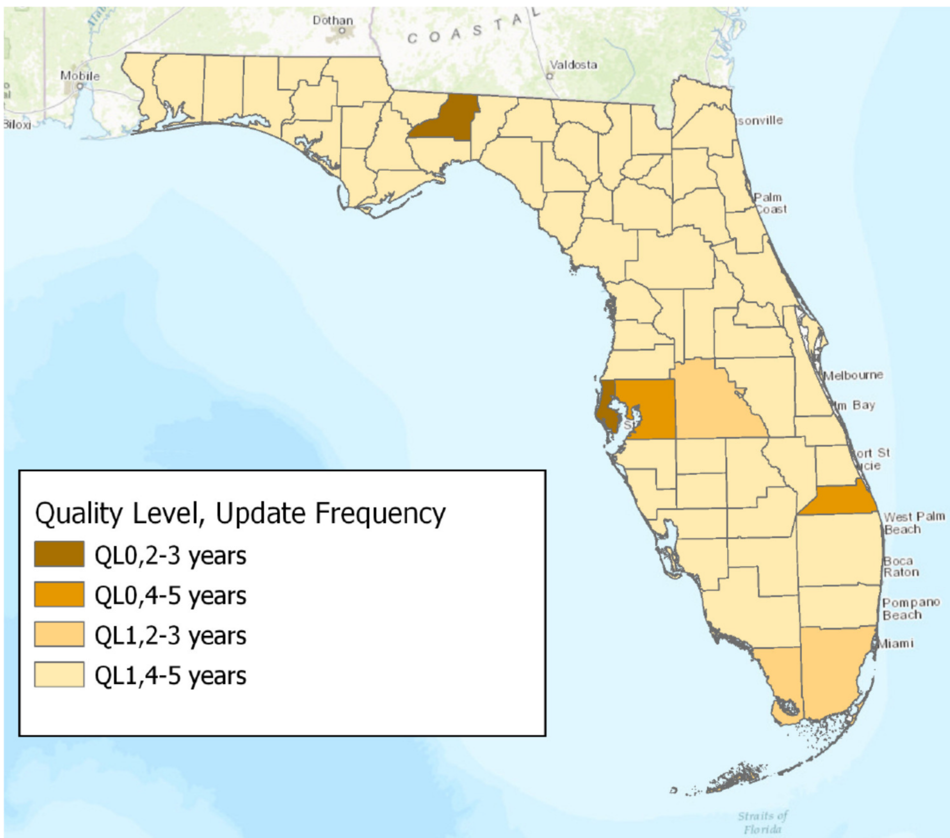

Figure 7. County-by-County Topographic LiDAR with highest Net Benefits; but this graphic is misleading because we did not have points of contact for most counties so they were not invited to participate in the questionnaire process. Only 8 counties submitted requirements and benefits.

For Scenario 1a, Dewberry concludes that county-by-county variations should not be considered and that QL1 updated every 2-3 years should be the statewide standard for the following reasons:

- ***Only 8 counties submitted requirements and benefits, largely because we lacked contact information and didn't know who to invite to participate in the questionnaire process***
- ***County-by-county variations for Florida are erratic and confusing for the same reason that state-by-state variations were confusing for the nationwide NEEA study, summarized in Appendix A (where Florida, alone, only justified QL5 data, but the national standard became QL2)***
- ***Individual counties in Florida can always "buy up" to QL0 if they are able to pay for the higher cost***

Scenario 2: Statewide Topobathymetric LiDAR, Nearshore Bathymetry Only

Table 35 provides the combined Cost-Benefit Analysis for all five Quality Levels, when using a uniform 0.8 Quality Level multiplier and a traditional 0.5 Update Frequency multiplier. The highest Net Benefits are a virtual tie between QL2B and QL0B, but Dewberry recommends QL0B statewide because it satisfies IHO Special Order standards and QL2B does not.

Table 35. Topobathymetric LiDAR Metrics when using a uniform 0.8 Quality Level Multiplier and a uniform 0.5 Update Frequency Multiplier

Option #	Quality Level	Update Frequency	Annual Total Costs	Annual Total Benefits	Benefit/Cost Ratio (BCR)	Net Benefits (Benefits - Costs)
1	QL0B	Annual	$31,072,820	$37,570,440	1.21	$6,497,620
2	QL0B	2-3 years	$12,429,128	$37,054,168	2.98	$24,625,040
3	**QL0B**	**4-5 years**	**$6,905,071**	**$35,173,116**	**5.09**	**$28,268,045**
4	QL0B	6-10 years	$3,884,103	$23,452,575	6.04	$19,568,472
5	QL0B	>10 years	$2,589,402	$11,819,753	4.56	$9,230,351
6	QL1B	Annual	$26,432,727	$30,386,560	1.15	$3,953,832
7	QL1B	2-3 years	$10,573,091	$29,883,543	2.83	$19,310,452
8	QL1B	4-5 years	$5,873,939	$28,290,048	4.82	$22,416,108
9	QL1B	6-10 years	$3,304,091	$18,847,306	5.70	$15,543,215
10	QL1B	>10 years	$2,202,727	$9,499,589	4.31	$7,296,862
11	QL2B	Annual	$30,742,411	$37,570,440	1.22	$6,828,029
12	QL2B	2-3 years	$12,296,964	$37,054,168	3.01	$24,757,204
13	**QL2B**	**4-5 years**	**$6,831,647**	**$35,173,116**	**5.15**	**$28,341,469**
14	QL2B	6-10 years	$3,842,801	$23,452,575	6.10	$19,609,773
15	QL2B	>10 years	$2,561,868	$11,819,753	4.61	$9,257,885
16	QL3B	Annual	$25,858,103	$30,386,560	1.18	$4,528,457
17	QL3B	2-3 years	$10,343,241	$29,883,543	2.89	$19,540,301
18	QL3B	4-5 years	$5,746,245	$28,290,048	4.92	$22,543,803
19	QL3B	6-10 years	$3,232,263	$18,847,306	5.83	$15,615,044
20	QL3B	>10 years	$2,154,842	$9,499,589	4.41	$7,344,747
21	QL4B	Annual	$21,835,731	$24,527,066	1.12	$2,691,335
22	QL4B	2-3 years	$8,734,292	$24,034,653	2.75	$15,300,360
23	QL4B	4-5 years	$4,852,385	$22,700,948	4.68	$17,848,563
24	QL4B	6-10 years	$2,729,466	$15,117,300	5.54	$12,387,833
25	QL4B	>10 years	$1,819,644	$7,619,399	4.19	$5,799,755

Table 36 provides the combined Cost-Benefit Analysis for all five Quality Levels, when using cost difference Quality Level multipliers (previously shown in Table 32) and a traditional 0.5 Update Frequency multiplier. Again, the highest Net Benefits are a virtual tie between QL2B and QL0B with 4-5 year updates (red outlines), but Dewberry would recommend QL0B statewide because it satisfies IHO Special Order standards with both the highest resolution and highest accuracy.

Table 36. Topobathymetric LiDAR Metrics when using cost difference Quality Level Multipliers and a uniform 0.5 Update Frequency Multiplier

Option #	Quality Level	Update Frequency	Annual Total Costs	Annual Total Benefits	Benefit/Cost Ratio (BCR)	Net Benefits (Benefits - Costs)
1	QL0B	Annual	$31,072,820	$37,570,440	1.21	$6,497,620
2	QL0B	2-3 years	$12,429,128	$37,054,168	2.98	$24,625,040
3	**QL0B**	**4-5 years**	**$6,905,071**	**$35,173,116**	**5.09**	**$28,268,045**
4	QL0B	6-10 years	$3,884,103	$23,452,575	6.04	$19,568,472
5	QL0B	>10 years	$2,589,402	$11,819,753	4.56	$9,230,351
6	QL1B	Annual	$26,432,727	$32,468,608	1.23	$6,035,880
7	QL1B	2-3 years	$10,573,091	$31,962,105	3.02	$21,389,014
8	QL1B	4-5 years	$5,873,939	$30,294,005	5.16	$24,420,066
9	QL1B	6-10 years	$3,304,091	$20,196,159	6.11	$16,892,068
10	QL1B	>10 years	$2,202,727	$10,178,846	4.62	$7,976,119
11	QL2B	Annual	$30,742,411	$37,493,211	1.22	$6,750,800
12	QL2B	2-3 years	$12,296,964	$36,977,496	3.01	$24,680,532
13	**QL2B**	**4-5 years**	**$6,831,647**	**$35,109,695**	**5.14**	**$28,278,048**
14	QL2B	6-10 years	$3,842,801	$23,419,516	6.09	$19,576,715
15	QL2B	>10 years	$2,561,868	$11,802,745	4.61	$9,240,877
16	QL3B	Annual	$25,858,103	$30,941,843	1.20	$5,083,740
17	QL3B	2-3 years	$10,343,241	$30,442,673	2.94	$20,099,432
18	QL3B	4-5 years	$5,746,245	$28,949,297	5.04	$23,203,052
19	QL3B	6-10 years	$3,232,263	$19,399,826	6.00	$16,167,563
20	QL3B	>10 years	$2,154,842	$9,773,674	4.54	$7,618,833
21	QL4B	Annual	$21,835,731	$25,078,151	1.15	$3,242,420
22	QL4B	2-3 years	$8,734,292	$24,592,445	2.82	$15,858,153
23	QL4B	4-5 years	$4,852,385	$23,421,910	4.83	$18,569,525
24	QL4B	6-10 years	$2,729,466	$15,772,423	5.78	$13,042,957
25	QL4B	>10 years	$1,819,644	$7,943,024	4.37	$6,123,379

The Cost-Benefit Analysis maxims pertain to bathymetric LiDAR, the same as topographic LiDAR:

- **In the absence of funding constraints, the "best value" for bathymetric LiDAR projects are those with the highest Net Benefits (see red outlines in Tables 35 and 36).**
- **Where there is a budget constraint, the benefit/cost ratio (BCR) should be used.**

For Scenario 2, Dewberry concludes that QL0B topobathymetric LiDAR, updated every 4-5 years, is the best alternative statewide when considering Net Benefits:

- ***Statewide Annual Costs: $6.9M (based on 4.5 years)***
- ***Statewide Annual Total Benefits: $35.2M (based on 4.5 years)***
- ***Statewide Annual Net Benefits: $28.3M (based on 4.5 years)***
- ***Benefit/Cost Ratio: 5.09***

Total Costs for multi-year acquisition: $31.1M.

If executed as a 3-year program, annual costs would be $10.4M

If executed as a 4-year program, annual costs would be $7.8M

If executed as a 5-year program, annual costs would be $6.2M

Although virtually tied with QL2B from a cost-benefit perspective, QL0B provides the highest accuracy and highest resolution seafloor definition and satisfies IHO Special Order standards whereas QL2B does not.

Scenario 2a: County-by-County Topobathy LiDAR, Nearshore Bathymetry Only

As shown at Figure 8, in a county-by-county assessment based on Net Benefits, every coastal county would justify QL0B updated every 4-5 years except for Hillsborough County which would justify a lower quality QL1B. This is an anomaly (outlier) caused totally by one MCA, with annual benefits of $900K, with requirements for QL4B; without this one requirement for lower quality topobathymetric LiDAR, Hillsborough County would also have justified QL0B, consistent with every other county in Florida.

This adds credence to Dewberry's prior argument that statewide assessment conclusions should be followed, rather than county-by-county assessment conclusions.

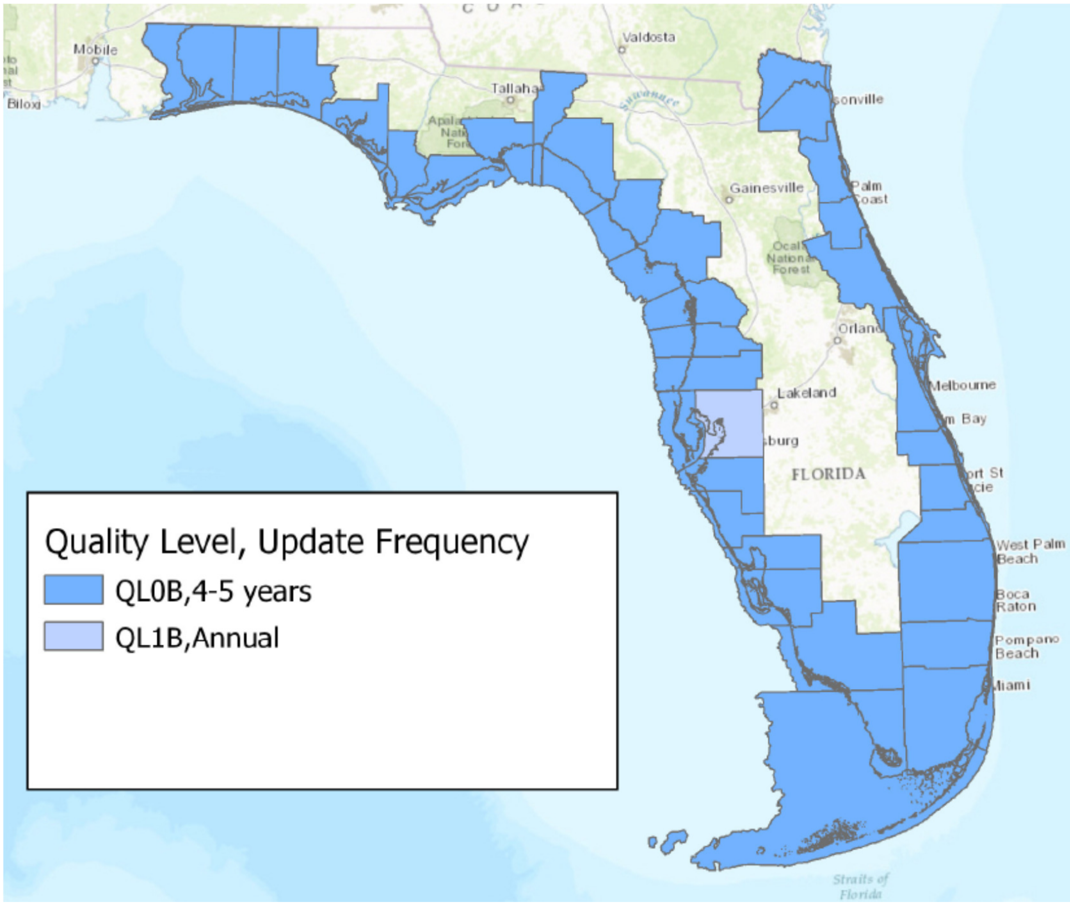

Figure 8. County-by-County Topobathymetric LiDAR with highest Net Benefits. Hillsborough County is an anomaly caused by one high value MCA requiring a lower quality level; this should be disregarded as an outlier because all other MCAs have consistent requirements statewide.

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Scenario 3: Statewide Topobathymetric LiDAR, Inland + Nearshore Bathymetry

Table 37 shows that there is a potential maximum net benefit of $28M per year from statewide QL2B topobathymetric LiDAR updated every 4-5 years. However the Benefit/Cost Ratio is relatively low (1.83), while the risks of project failure are very high because of inland water turbidity.

For Scenario 3, when considering that topobathymetric LiDAR will not map bathymetric surfaces in most of Florida's rivers lakes and ponds because of turbidity, Dewberry does not recommend Scenario 3 except as a "buy-up" option in selected areas where waters are known to be clear.

Table 37. Statewide (Inland plus Nearshore) Topobathymetric LiDAR Metrics when using cost difference Quality Level Multipliers and a uniform 0.5 Update Frequency Multiplier

Option #	Quality Level	Update Frequency	Annual Total Costs	Annual Total Benefits	Benefit/Cost Ratio (BCR)	Net Benefits (Benefits - Costs)
1	QL0B	Annual	$153,881,536	$64,945,500	0.42	-$88,936,036
2	QL0B	2-3 years	$61,552,615	$64,376,750	1.05	$2,824,135
3	QL0B	4-5 years	$34,195,897	$61,875,875	1.81	$27,679,978
4	QL0B	6-10 years	$19,235,192	$41,337,938	2.15	$22,102,745
5	QL0B	>10 years	$12,823,461	$20,786,469	1.62	$7,963,007
6	QL1B	Annual	$130,902,463	$52,286,000	0.40	-$78,616,463
7	QL1B	2-3 years	$52,360,985	$51,741,000	0.99	-$619,985
8	QL1B	4-5 years	$29,089,436	$49,673,000	1.71	$20,583,564
9	QL1B	6-10 years	$16,362,808	$33,169,000	2.03	$16,806,192
10	QL1B	>10 years	$10,908,539	$16,680,500	1.53	$5,771,961
11	QL2B	Annual	$152,245,256	$64,945,500	0.43	-$87,299,756
12	QL2B	2-3 years	$60,898,102	$64,376,750	1.06	$3,478,648
13	**QL2B**	**4-5 years**	**$33,832,279**	**$61,875,875**	**1.83**	**$28,043,596**
14	QL2B	6-10 years	$19,030,657	$41,337,938	2.17	$22,307,281
15	QL2B	>10 years	$12,687,105	$20,786,469	1.64	$8,099,364
16	QL3B	Annual	$128,056,757	$52,286,000	0.41	-$75,770,757
17	QL3B	2-3 years	$51,222,703	$51,741,000	1.01	$518,297
18	QL3B	4-5 years	$28,457,057	$49,673,000	1.75	$21,215,943
19	QL3B	6-10 years	$16,007,095	$33,169,000	2.07	$17,161,905
20	QL3B	>10 years	$10,671,396	$16,680,500	1.56	$6,009,104
21	QL4B	Annual	$108,136,817	$42,046,400	0.39	-$66,090,417
22	QL4B	2-3 years	$43,254,727	$41,520,400	0.96	-$1,734,327
23	QL4B	4-5 years	$24,030,404	$39,807,200	1.66	$15,776,796
24	QL4B	6-10 years	$13,517,102	$26,574,600	1.97	$13,057,498
25	QL4B	>10 years	$9,011,401	$13,364,100	1.48	$4,352,699

In addition to the recommended statewide LiDAR acquisition strategy, as noted previously in Table 22, 30% of study respondents expressed a requirement for integration between elevation data and shoreline updates. NOAA is responsible for updating the Continuously Updated Shoreline Product (CUSP) using high-resolution LiDAR and orthoimagery. The CUSP is currently incomplete in Florida, notably along portions of the western coast as well as the Everglades and Florida Keys. It is recommended that the State coordinate with NOAA on the state's LiDAR acquisition program and its timing as well as promote the availability to statewide users of the updated CUSP as the new Florida LiDAR data are reflected in it.

Task 6: Identification of Potential Public and Private Partnerships for Future Funding

For Scenario 1, the total estimated cost for statewide QL1 topographic LiDAR is $19.9M and for Scenario 2, the total estimated cost for statewide nearshore QL0B topobathymetric LiDAR is $31.1M. This totals nearly $51M over whichever update cycle is chosen by the state.

Once Florida's LiDAR program has been well defined, it's time to start building partnerships. A perfect partnership is one that distributes the cost of a program to all those who benefit from such a program. Dewberry has seen several very successful partnerships in the past -- those partnerships have typically been federal and state/local partnerships -- but Florida has the opportunity to include one additional partner, the private sector as well as two additional funding strategies: Florida needs to include Federal Grants and then take those collective funds and apply for a USGS 3DEP BAA Grant. By leveraging all these partnerships and funding strategies, Florida will have the opportunity to set a new standard for States.

This "pass the hat" model has been very successful in the past, most notably with the State of Alaska, where multiple Federal and State partners have combined resources and contributed more than $60M to date. It should be noted the State of Alaska program only includes some of the proposed partners and funding strategies; their program does not include private sector funding or Federal Grants.

We see the opportunity to build a three-way partnership as well as incorporate two additional funding strategies to finance a Florida Statewide LiDAR program.

- **State and Local Partners** – create a pool of funds from state and local governments – especially from the five Water Management Districts which have the most mission critical requirements for accurate and up-to-date LiDAR datasets. These funds can be generated from direct state funding (the state should request a line item for funding) as well as additional State Agency funds from FDOT, FL DEP, etc. The state should lean heavily on Water Management Districts, counties and cities that have requirements; they need to understand that their requirements will be met at a lower cost, because their funds are being leveraged.
- **Federal Agencies** – create a pool of Federal funds with agencies such as FEMA, USGS, USDA, NOAA, USACE, FAA, etc. These Agencies have requirements in the State of Florida; they should be documented and prioritized and then funded accordingly. Like cities and counties, they need to understand that their requirements will be met and, by leveraging their funds, they too will get more for their money.
- **Private Sector** – create a pool of private sector funds from companies such as Florida Power & Light, Gulf Power, CSX Railroad, etc.; although funding is unknown, these private firms are currently spending funds on acquiring LiDAR in Florida, and they should be approached about partnering to have their requirements met through this statewide initiative. Engineering firms are already using LiDAR for geological analyses, for construction planning, and to support the oil and gas and mining industries, for example. Land surveying firms will someday realize the benefits in using high-accuracy, high-resolution LiDAR for everyday surveying practices; similar to GPS surveys of the 1980's -- originally seen as a threat to land surveyors who today see GPS

as their present and future -- the time will come where some field-run topographic surveys or FEMA Letters of Map Amendment (based on Elevation Certificates) will use the same authoritative LiDAR data used for flood studies, especially for houses that don't have basements, as in most of Florida. Whereas land surveyors may today see LiDAR as a threat to their "bottom line," those who succeed in the long term will realize that the most authoritative, high-accuracy, high-resolution LiDAR data statewide will enable them to deliver superior topographic survey products at lower costs. This may require changes to Florida statutes for Professional Surveyors and Mappers, but Dewberry predicts that there will soon be a groundswell of support for LiDAR as it becomes a standard tool for engineers and surveyors.

- **Federal Grants** – apply for Federal grants to include; FEMA Mitigation Grant, NOAA Resiliency Grant, USDOT MAPS 21 Grant, etc. By pooling these funds together, all of these grant dollars will add to the dollars required annually to fund a Florida statewide LiDAR mapping program
- And lastly, take all these collected funds and apply for a **USGS 3DEP BAA Grant** to fully leverage all these collective funds.

Dewberry feels this program should follow a very specific process to build partnerships, apply for Federal Grants, etc., but we think these processes are worth the effort. Figure 9 is the process we recommend for this program:

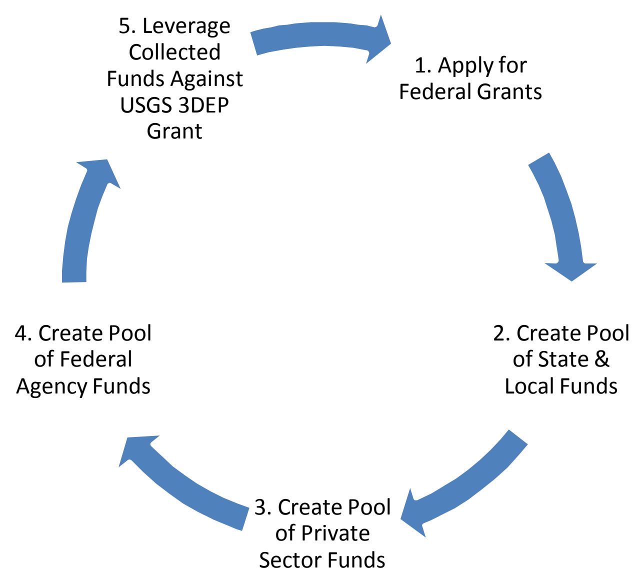

Figure 9. Public-Private Partnership Cycle

Dewberry acknowledges this is not a traditional approach to funding, in particular the inclusion of the private sector. Traditionally the government is not good at accepting private contributions and some additional research must be conducted to understand the best way for transferring private sector funds to the public sector, but this model has been successful before, in particular with the National Park Service and Restore Act Funding (BP oil spill). Both NPS and Restore Act created quasi government/private entities to collect and manage private funding that was/is eventually used to fund public infrastructure projects. Congressman Rob Bishop (R-Utah) sponsored the NPS bill to help address some of our national parks' critical repair needs; it would expand public-private partnerships in national parks and fund a national parks endowment. NOAA has the Gulf Coast Restoration Trust Fund as a mechanism to distribute funding. Adding the private sector and Federal Grants could potentially generate as much as 20%-30% of the necessary funding for this program. Dewberry sees this program and new strategy as being able to deliver the results in Figure 10 for a $51M LiDAR acquisition program whether spread over 3, 4 or 5 years.

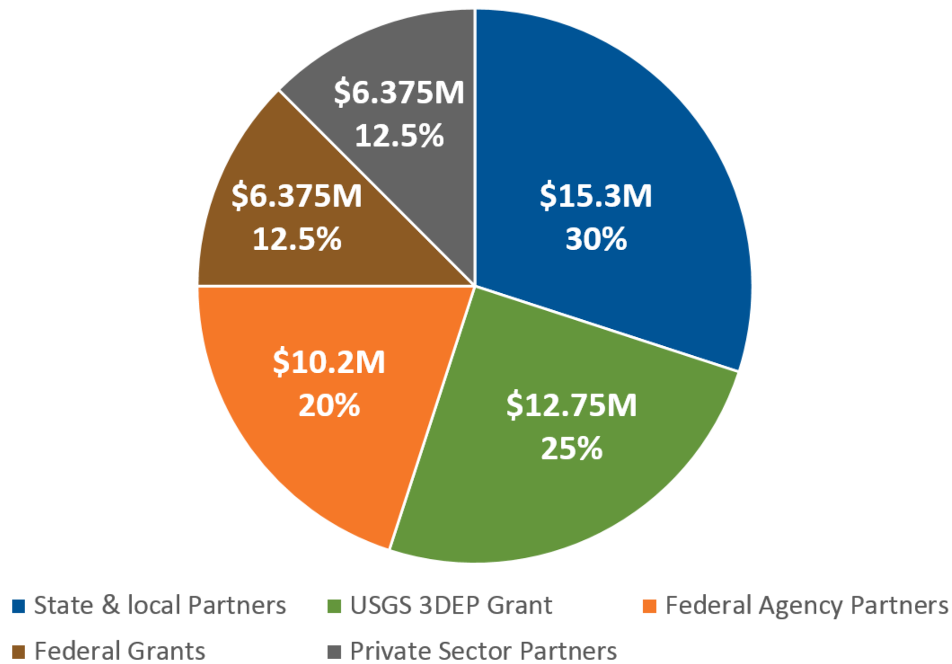

Figure 10. Proposed Targets for Public-Private Partnerships

Florida's Strategic Principles

In evaluating how to map Florida most effectively in any multi-year cycle, Dewberry reviewed Florida's Strategic Principles, detailed on pages 7 and 8, and summarized as follows:

1. Large, seamless, temporally consistent
2. Consistent with existing aerial photography flight schedule
3. Systematic collection
4. Prioritize existing data gaps
5. Prioritize major business uses (e.g., flood risks and water supply and quality from Table 7).

Acquisition Plan A – fill existing data gaps first. Figure 1 shows existing LiDAR data gaps in red. Areas could be prioritized to map the red areas first, amber areas second, and green areas third. However, Plan A (consistent with Principle 4) would violate all four of the other principles as annual acquisition areas would be extremely inefficient.

Acquisition Plan B – map each county with LiDAR the year prior to when that county is scheduled for new aerial photography and update of digital orthophotos (see Figure 11), enabling the best elevation data to be available in time for use in orthorectification. Plan B is consistent with Principle 2 and reasonably consistent with Principles 1 and 3.

Acquisition Plan C – map all counties in the same Florida State Plane Coordinate System in the same year. Figure 12 shows what that would look like for a 3-year cycle. With a 4-year cycle, the largest east SPCS zone could be split between two years while the two smaller zones are completed in a single year. Alternatively, with a 5-year update cycle, the larger eastern and northern SPCS zones could be split between two years each while the smaller western zone is completed in a single year. With Plan C, the area collected in any year would be large, seamless and temporally consistent. Plan C would be consistent with Principles 1 and 3, but it would be inconsistent with Principles 2 and 4.

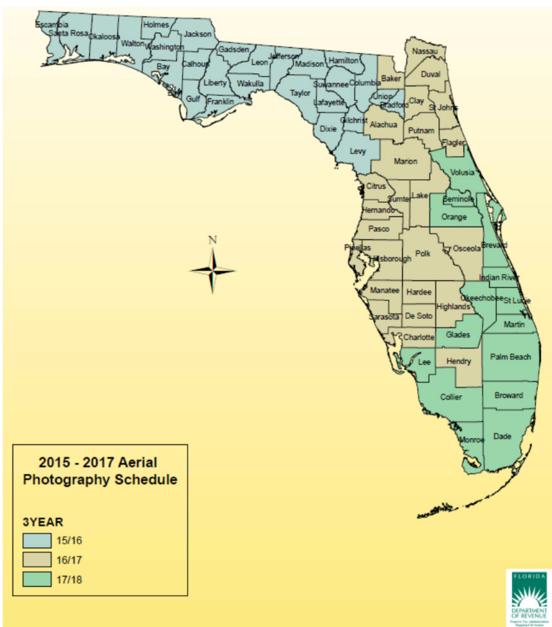

Figure 11. Acquisition Plan B, based on Florida's existing 3-year aerial photography update schedule. Aerial photography requires elevation data for update of digital orthoimagery.

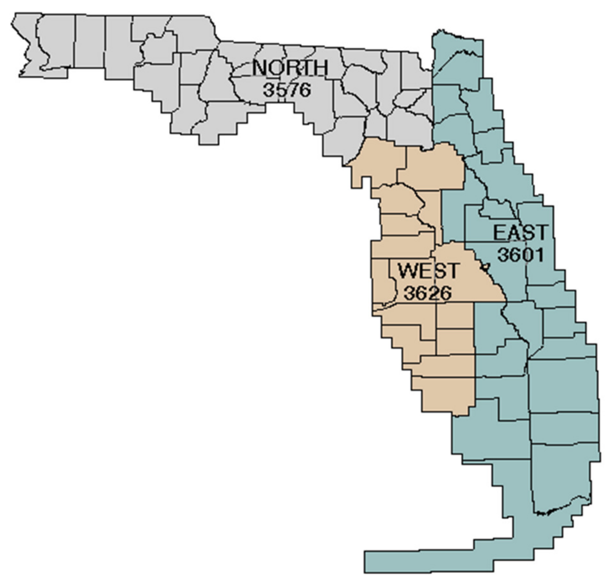

Figure 12. Acquisition Plan C, based on Florida's existing State Plane Coordinate System zones where all data are processed using the same map projection parameters within each zone.

Acquisition Plan D – map entire Water Management Districts in the same year so there are no inconsistencies in hydrologic modeling as a result of different LiDAR datasets acquired in different years (see Figure 13). Plan D was recommended by participants at the LiDAR Workshop conducted by the Florida Region of the American Society for Photogrammetry and Remote Sensing (ASPRS) on June 22, 2017.

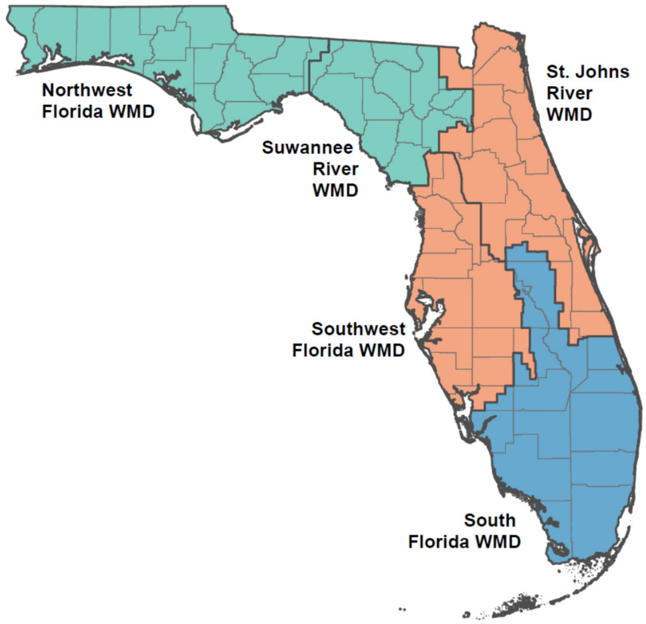

Figure 13. Acquisition Plan D where all LiDAR data in any year are acquired of entire Water Management Districts for consistent hydrologic modeling

For a 3-year cycle, Florida could consider the following sequence, for example:

- Year 1, all of the South Florida WMD.
- Year 2, all of the Southwest Florida and St. Johns River WMDs
- Year 3, all of the Northwest Florida and Suwannee River WMDs

Dewberry recommends Plan D because accurate and consistent hydrologic modeling is critical for all five of the major LiDAR Business Uses listed in Table 7. Plan D best addresses Principles 1, 3, 4 and 5, and by acquiring the southernmost colored areas first, Plan D would also fill in all gaps (Principle 2) within the first two years.

Of these four acquisition plans for a multi-year acquisition cycle, Dewberry considers Plan D to be the most efficient while best addressing all of Florida's Strategic Principles. Plan D best addresses Principles 1, 3, 4 and 5. Within two years, Principle 2 will also be satisfied by filling in the gaps that currently exist in South Florida, Southwest Florida, and St. Johns River WMDs.

For the first 3-year acquisition cycle, areas already acquired with QL1 LiDAR data should be excluded, to be updated with following 3-year acquisition cycle.

Appendix A – NEEA Lessons Learned

The National Enhanced Elevation Assessment (NEEA), completed in 2012 by Dewberry for a consortium of government agencies led by the U.S. Geological Survey (USGS), analyzed all 50 states and U.S. territories by 1-degree x 1-degree cells (latitude and longitude) to determine which of five elevation data Quality Levels (QL's) and which of five update frequencies would be best for each cell. Dewberry initially analyzed requirements and benefits separately from three user groups: Federal agencies, states, and non-governmental organizations.

Federal Agencies Only

Figure A.1 shows the results from Federal agency requirements and benefits only. It shows that, for Florida, the Federal Agency net benefits would justify QL2 LiDAR updated every 6-10 years for most cells, with a few exceptions for isolated cells.

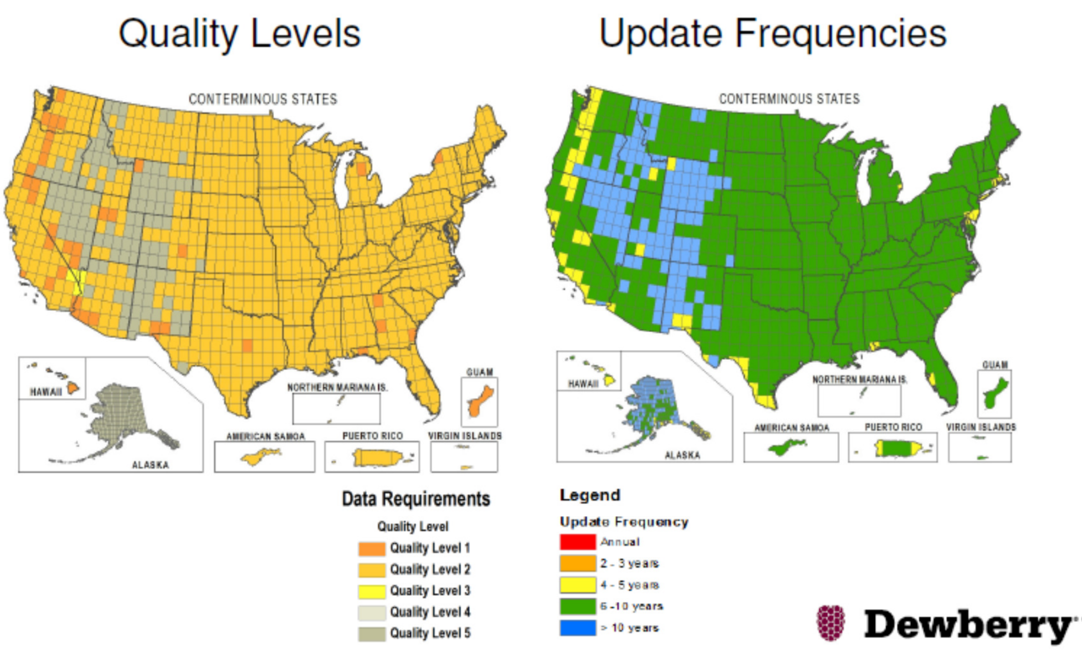

Figure A.1 – Highest Net Benefits by Cell when considering Federal Agency Input Only

States Only

Figure A.2 shows the results from state-submitted requirements and benefits only, It show that, for Florida, the highest net benefits would be for QL5 IFSAR, updated every 6-10 years – <u>even though there were no requirements for QL5 IFSAR among the 11 Mission Critical Activities (MCAs) documented</u>. This happened because the cost for statewide QL3 LIDAR was $15.8M with annual benefits of $5.37M – but only if each of the MCA's received the QL and Update Frequency required. QL5 IFSAR showed better net benefits than the least expensive QL3 LiDAR for the following reasons:

1. Of Florida's 11 MCA Quality Level requirements, 3 required QL1, 5 required QL2, and 3 required QL3. Benefits were reduced by 50% for every drop in Quality Level below the required level. Therefore, for the three MCAs requiring QL1, their benefits would drop to only 25% for a QL3 LiDAR scenario; and for the five MCAs requiring QL2, their benefits would drop to 50% for QL3 LiDAR.
2. Of Florida's 11 MCA Update Frequency requirements, two were event-driven, meaning their benefits were cut in half; three MCAs required 2-3 year update frequency meaning their benefits were cut to 1/4th for a 6-10 year scenario; and four MCAs required 4-5 year update frequency meaning their benefits were cut in half for a 6-10 year scenario.
3. The estimated cost of QL3 LiDAR was $240.64 per square mile, compared with $80/square mile for QL5 IFSAR. By the time the MCA benefits were reduced because of reduced values explained in 1 and 2, the lower cost of QL5 IFSAR appeared to show the best net benefits for Florida and a higher Return on Investment.

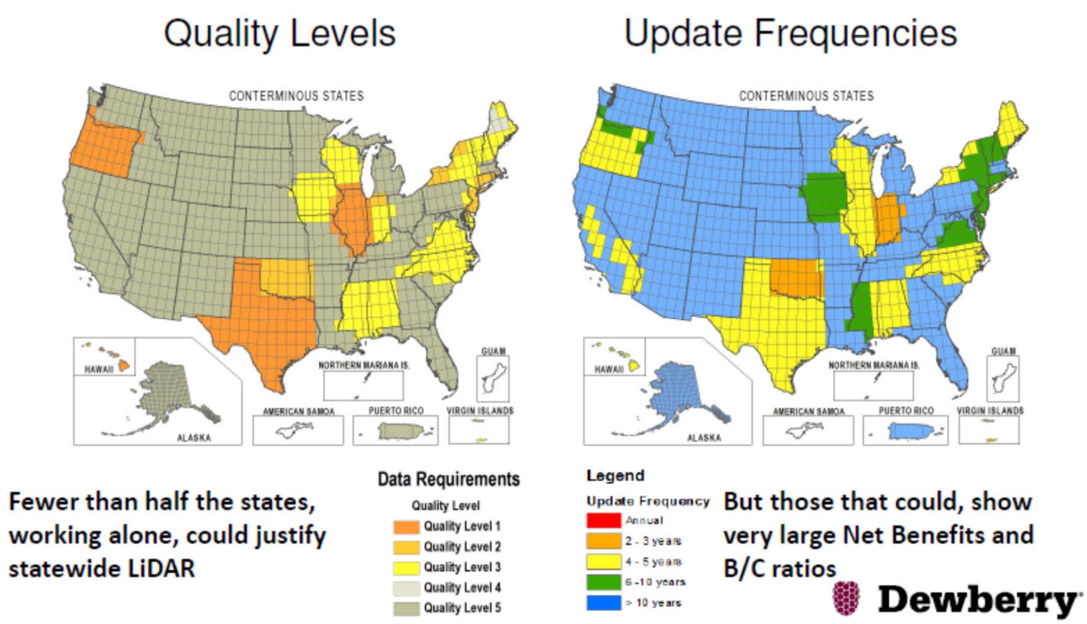

Figure A.2 – Highest Net Benefits by Cell when considering State Input Only

Non-Governmental Organizations Only

Figure A.3 shows the results from non-governmental requirements and benefits only, It show that, for most cells in Florida, the highest net benefits would be for QL5 IFSAR, updated every 6-10 years – <u>even though there was only one non-governmental requirement for QL5 IFSAR (for wind-farm siting and design)</u>. A few isolated 1-degree cells justified QL3 LiDAR. The reasons for QL5 IFSAR are similar to those explained above for state only requirements and benefits.

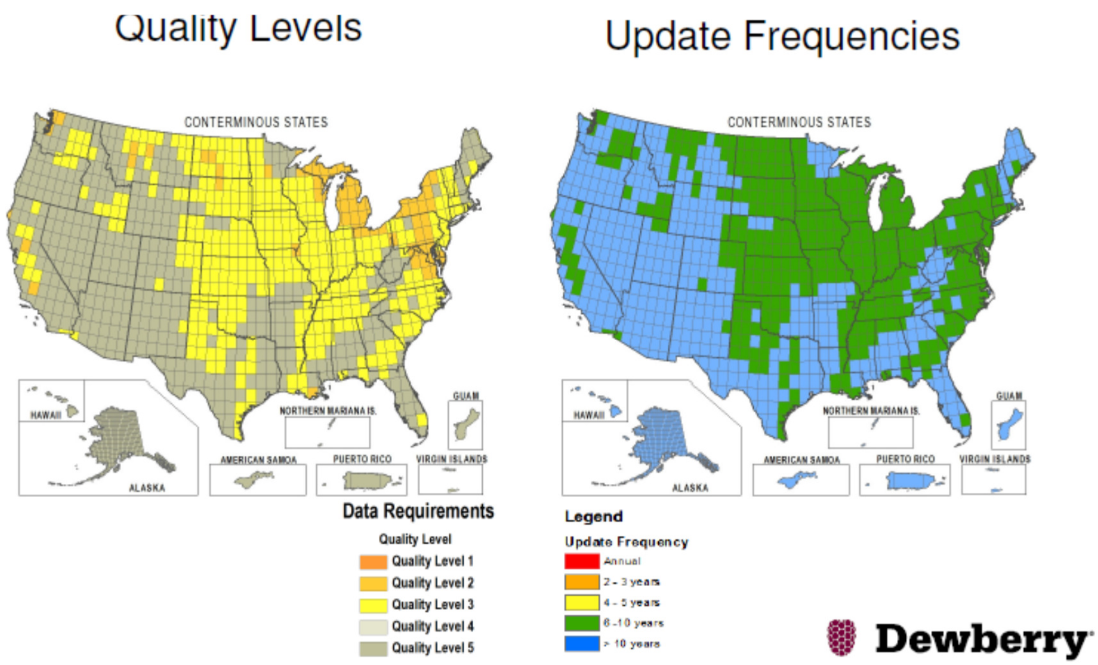

Figure A.3 – Highest Net Benefits by Cell when considering Non-Governmental Organizations Only

Combined Federal, State, and Non-Governmental

Figure A.4 shows the combined results from Federal, state and non-governmental organization requirements and benefits. It shows that, for Florida, the net benefits would justify QL2 LiDAR updated every 6-10 years, with a single 1-degree cell justifying QL1 LiDAR.

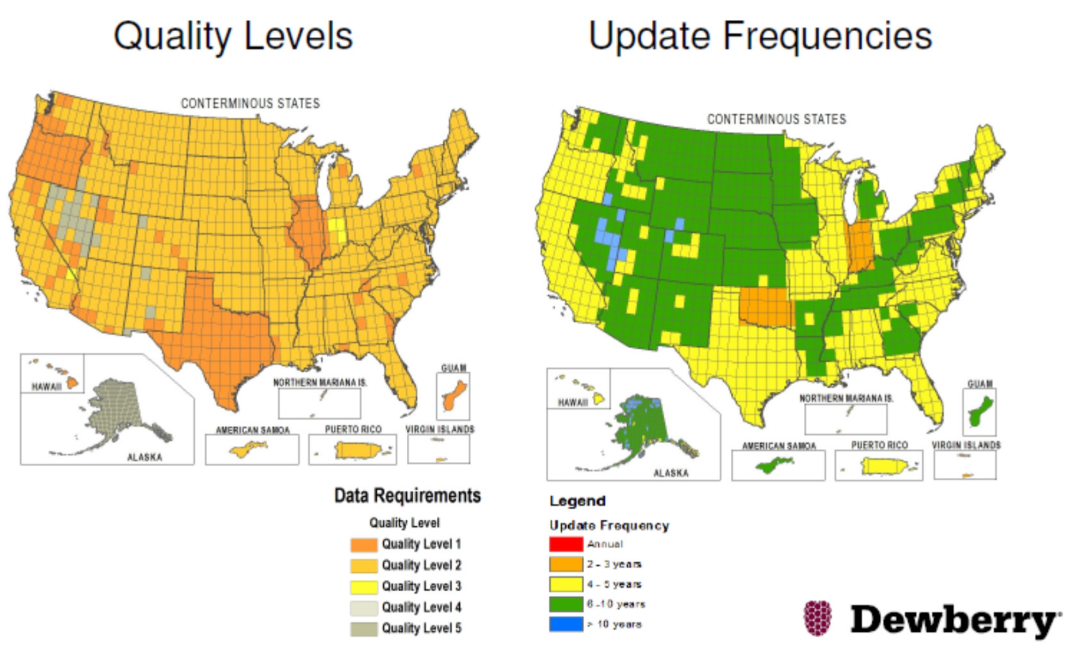

Figure A.4 – Highest Net Benefits by Cell when considering Federal, State and Non-Governmental Organizations Combined

NEEA Statistical Lessons Learned

Table A.1 summarizes the major statistics from these separate and combined analyses. The overall lessons learned are summarized as follows:

1. If all three user groups acted alone, total annual costs would be $289M, total annual benefits would be $891, total annual net benefits would be $602M, and the Benefit/Cost ratio would be 3.079. Programs are inefficient when stakeholders do not work together to solve common needs.
2. By combining their programs, the total annual costs would be $213M, the annual benefits would be $1008M, the annual net benefits would be $795M, and the Benefit/Cost ratio would be 4.728; this is vastly superior in that costs are lower and benefits are higher from partnerships.
3. Based on its NEEA input, If Florida had acted alone, it could not justify any LiDAR Quality Level, but showed the best net benefits from QL5 IFSAR updated every 6-10 years. By combining all requirements and benefits, the NEEA concluded that QL2 LiDAR, updated on an 8-year cycle, would be the nationwide standard, with "buy-up" options for those with greater needs and able to pay the cost difference.

Table A.1 – Summary Statistics from the National Enhanced Elevation Assessment

User Group	Annual Costs	Annual Benefits	Annual Net Benefits	Benefit/Cost Ratio	Florida Only	
					Quality Level	Update Frequency
Federal	$124M	$252M	$128M	2.031	QL2	6-10 years
States	$105M	$506M	$401M	4.820	QL5	6-10 years
Non-Gov.	$60M	$133M	$73M	2.206	QL5	6-10 years
Subtotal	$289M	$891M	$602M	3.079	QL2	4-5 years
Combined	$213M	$1,008M	$795M	4.728	QL2	6-10 years