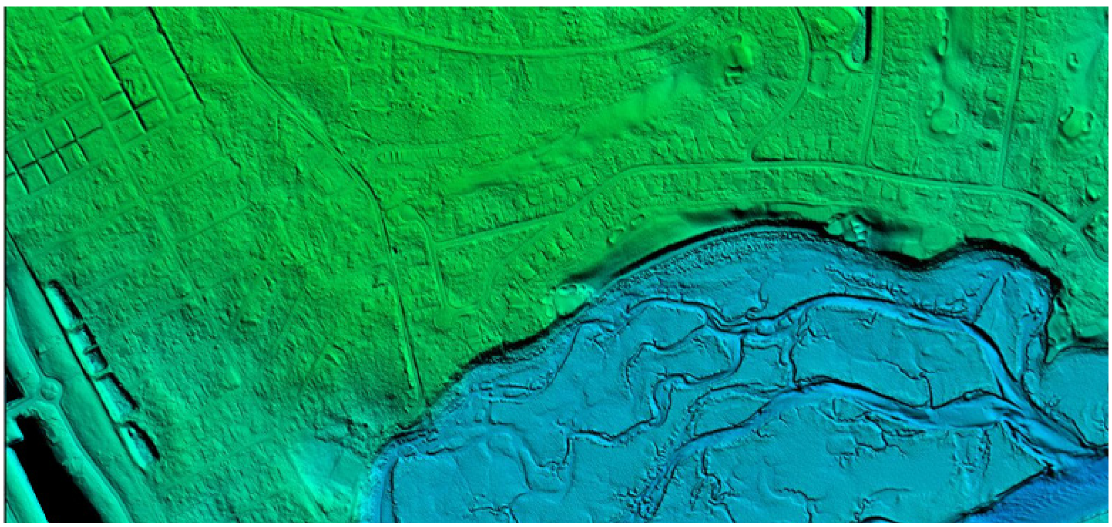
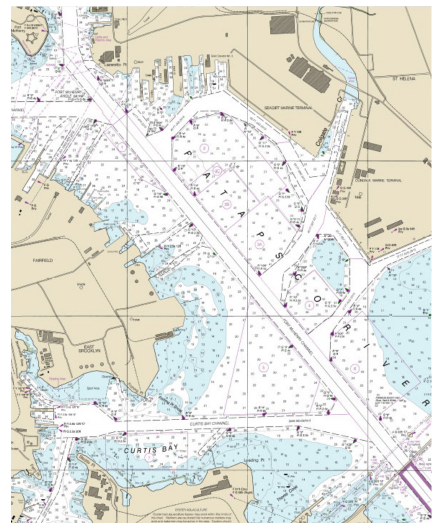
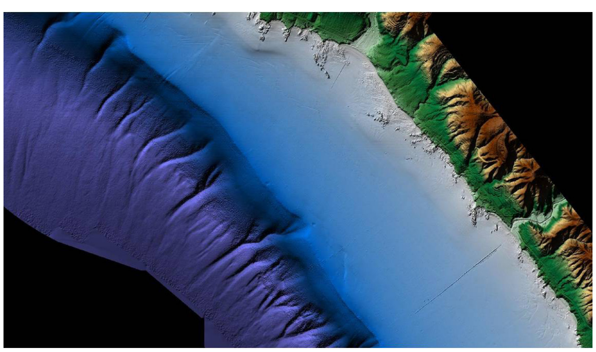
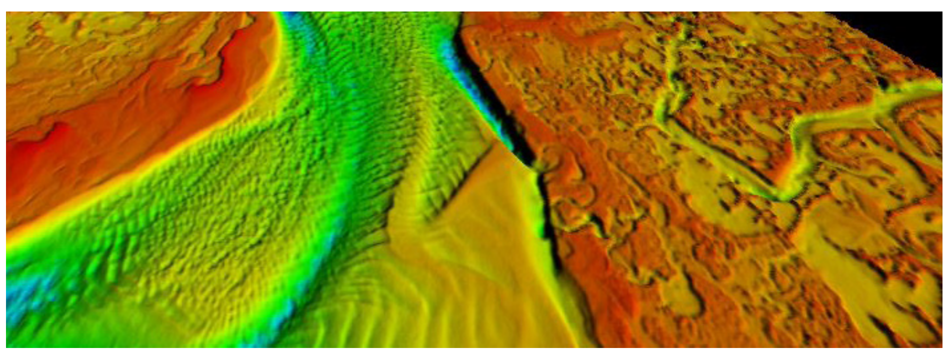
3D NATION ELEVATION REQUIREMENTS AND BENEFITS STUDY

SEPTEMBER 15, 2022









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Acronyms and Abbreviations

2D	2-Dimensional
3D	3-Dimensional
3DEP	3D Elevation Program
3DHP	3D Hydrography Program
3DNTM	3D National Topography Model
AGL	Above Ground Level
AINS	Aided Inertial Navigation System
AIS	Automatic Identification System
ALB	Airborne Lidar Bathymetry
AOI	Area of Interest
APD	Avalanche Photodiode
APHIS	Animal and Plant Health Inspection Service
ARS	Agricultural Research Service
ASCII	American Standard Code for Information Interchange
ASPRS	American Society for Photogrammetry and Remote Sensing
ASV	Autonomous Surface Vessel
AT	Aerial Triangulation
BAA	Broad Agency Announcement
B/C	Benefit/Cost
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BOEM	Bureau of Ocean Energy Management
BOR	Bureau of Reclamation
BU	Business Use
CDC	Centers for Disease Control and Prevention
CIR	Color Infrared
CMTS	U.S. Committee on the Marine Transportation Service
CONUS	Continental U.S.
CSB	Crowd-sourced Bathymetry
CSV	Crewed Surface Vessel
CZMIL	Coastal Zone Mapping and Imaging Lidar
DAV	Data Access Viewer
DCDB	Data Center for Digital Bathymetry
DEM	Digital Elevation Model

DG	Direct georeferencing
DHS	Department of Homeland Security
DInSAR	Differential Interferometric Synthetic Aperture Radar
DISDI	Defense Installations Spatial Data Infrastructure
DoD	Department of Defense
DOL BLS	Department of Labor Bureau of Labor Statistics
DS	Distributed Scatterer
DSM	Digital Surface Model
DTM	Digital Terrain Model
DTRA	Defense Threat Reduction Agency
ECS	Extended Continental Shelf
EEZ	Exclusive Economic Zone
ENC	Electronic Nautical Chart
ENOW	Economics: National Ocean Watch
EPA	Environmental Protection Agency
EPT	Entwine Point Tile
FAA	Federal Aviation Administration
FAQ	Frequently Asked Question
FBI	Federal Bureau of Investigation
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FGDC	Federal Geographic Data Committee
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOV	Field of Vision
FRA	Federal Railway Administration
FSA	Farm Service Agency
FTP	File Transfer Protocol
FWS	Fish and Wildlife Service
GCP	Ground Control Point
GDB	Geodatabase
GDP	Gross Domestic Product
GEBCO	General Bathymetric Chart of the Ocean
GHz	Gigahertz
GIS	Geographic Information System
GLC	Great Lakes Commission
GLOS	Great Lakes Observing System

GML	Geiger Mode Lidar
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPSC	Geospatial Product and Service Contracts
GPU	Graphic Processing Unit
GRiD	Geospatial Repository and Data Management System
GSD	Ground Sample Distance
HD	High Density
HHM	Hydrographic Health Model
HRBS	National Hydrography Requirements and Benefits Study
HTTPS	Hypertext Transfer Protocol Secure
HUC	Hydrologic Unit Code
IBWC	International Boundary and Water Commission
ICESat	Ice, Cloud, and Land Elevation Satellite
IfSAR	Interferometric Synthetic Aperture Radar
IHO	International Hydrographic Organization
IJC	International Joint Commission
IMG	Erdas Imagine
IMU	Inertial Measurement Unit
INFOMAR	Integrated Mapping for the Sustainable Development of Ireland's Marine Resource
InSAR	Interferometric Synthetic Aperture Radar
IT	Information Technology
IWG-OCM	Interagency Working Group on Ocean and Coastal Mapping
JALBTCX	Joint Airborne Lidar Bathymetry Technical Center of Expertise
K_d	Diffuse attenuation coefficient of light underwater
kHz	Kilohertz
LARS	Launch and Recovery System
Lidar	Light detection and ranging
LML	Linear Mode Lidar
LNM	Linear Nautical Miles
LTS	Long Term Support
MARAD	Maritime Administration
MBES	Multi-Beam Echo Sounder
MCA	Mission Critical Activity
MHW	Mean High Water
MHHW	Mean Higher High Water
MHz	Megahertz
MLLW	Mean Lower Low Water

MMPGIS	Marine Minerals Program GIS
MSL	Mean Sea Level
NALL	Navigational Area Limit Line
NAPGD	North American-Pacific Geopotential Datum
NASA	National Aeronautics and Space Administration
NAVD	North American Vertical Datum
NB	Net Benefit
NCEI	National Center for Environmental Information
NCMS	National Coastal Mapping Strategy
NEEA	National Enhanced Elevation Assessment
NEXT	NCEI Data Extract System
NGA	National Geospatial-Intelligence Agency
NGO	Non-governmental Organization
NGS	National Geodetic Survey
NHD	National Hydrography Dataset
NIR	Near Infrared
NLCD	National Land Cover Database
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
NOMEC	National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone
NOS	National Ocean Service
NRC	Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NVA	Non-vegetated Vertical Accuracy
OCM	Office for Coastal Management
OCS	Office of Coast Survey
OGC	Open Geospatial Consortium
OLCI	Ocean and Land Color Instrument
OMB	Office of Management and Budget
ORI	Orthorectified Radar Image
ORNL	Oak Ridge National Laboratory
OSMRE	Office of Surface Mining Reclamation and Enforcement
PDBS	Phase Differencing Bathymetric Sonar
PHMSA	Pipeline and Hazardous Materials Safety Administration
POC	Point of Contact
PORTS	Physical Oceanographic Real-Time System®

PPSM	Points Per Square Meter
PRF	Pulse Repetition Frequency
PS	Permanent Scatterer
PSInSAR	Permanent Scatterer InSAR
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
QL	Quality Level
QLB	Bathymetry Quality Level
QPS	Quality Planning Software
RAM	Random Access Memory
RAMMS	Rapid Airborne Multi-beam Mapping System
RGB	Red/Green/Blue
$RMSD_z$	Vertical Root mean Square Deviation
$RMSE_r$	Vertical Root Mean Square Error
$RMSE_z$	Radial Root Mean Square Error
RNC	Raster Nautical Chart
ROI	Return on Investment
RPH	Roll-Pitch-Heave
SAR	Synthetic Aperture Radar
SBES	Single-Beam Echo Sounder
SDB	Satellite Derived Bathymetry
SfM	Structure from Motion
SI	Smithsonian Institution
SLR	Sea Level Rise
SNM	Square Nautical Miles
SOLAS	Safety of Life at Sea
SPL	Single Photon Lidar
TB	Terrabyte
TDS	Topographic Data Services
THU	Total Horizontal Uncertainty
TNM	The National Map
TVA	Tennessee Valley Authority
TVU	Total Vertical Uncertainty
UAS	Unmanned Aerial System
UAV	Uncrewed Aerial Vehicle
U.S.	United States
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force

USARC	U.S. Arctic Research Commission
USBR	U.S. Bureau of Reclamation
USCG	U.S. Coast Guard
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USIEI	U.S. Interagency Elevation Inventory
USMC	U.S. Marine Corps
USN	U.S. Navy
USV	Uncrewed Surface Vessel
UxS	Unmanned System
V-Datum	National Vertical Datum Transformation Tool
VG	Vertical Gyro
VVA	Vegetated Vertical Accuracy

Table of Contents

3D Nation Elevation Requirements and Benefits Study Final Report

1. Executive Summary

1.1. Overview

The National Oceanic and Atmospheric Administration (NOAA) Office of Coast Survey (OCS), the U.S. Geological Survey (USGS), and partner mapping agencies on the 3D Elevation Program (3DEP) along with the Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM) are working to improve the technology, systems, data, and services that provide information about three-dimensional (3D) elevation data and related applications within the United States (U.S.). By learning more about business uses and associated benefits that would be realized from improved 3D elevation data, for both heights and depths, the agencies will be able to prioritize and direct investments that will best serve user needs. This 3D Nation Elevation Requirements and Benefits Study will help federal mapping agencies to develop and refine future program alternatives for enhanced 3D elevation data to meet many federal, state, and other national business needs.

The goals of this study are to capture inland, nearshore, and offshore topographic and bathymetric elevation data requirements and benefits and understand how those requirements and benefits dovetail in the nearshore coastal zone. This study builds upon the 2012 National Enhanced Elevation Assessment (NEEA) by collecting new and updated information on requirements and benefits for high resolution topographic elevation data and identifying requirements for repeat data coverage in the years beyond the planned initial 8-year acquisition program. Furthermore, this study aims to capture the information about the need for, and value of elevation data using a sensor agnostic and technology neutral approach. The information captured in this study was categorized into a set of national Business Uses associated with elevation data. The data were then used to evaluate the benefits of successfully supporting those Business Use requirements within the context of major national mapping programs.

In addition to the NEEA, several prior studies and strategies performed by the Government informed this study including the 3DEP Call for Action; the National Coastal Mapping Strategy 1.0 (NCMS 1.0); the National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (NOMEC Strategy); and the USGS 3D National Topography Model Call for Action: 3D Hydrography Program.

1.2. 3D Nation Concept

The vision of a 3D Nation is to make communities more resilient and the U.S. economy more competitive by building a modern, accurate elevation foundation from our highest mountains to our deepest oceans. 3D Nation unites terrestrial and ocean/coastal mapping agencies in common purpose to achieve an authoritative national geospatial foundation in support of national mapping needs.

3D Nation serves as a unifying structure for all national elevation efforts and provides a consistent set of standards and objectives to ensure public access to an accurate, authoritative national elevation dataset.

1.3. 3D Nation Study Context

Four areas were defined and used to organize and map the areas of interest of the study participants as follows.

Inland Topography - Inland topography refers to data collected on land, and may include the exposed land surface, features and objects on land such as building structures and vegetation, as well as bare earth topography concealed under vegetation. Inland topography typically includes the beach area, sometimes as far out as the Mean Lower Low Water (MLLW) line, if tidal conditions permit, to map all land areas that are not submerged.

Inland Bathymetry - Inland bathymetry refers to data collected on the bottoms of lakes, reservoirs, and rivers and may include submerged features such as structures, objects, or vegetation.

Nearshore Bathymetry - For the purpose of this study, nearshore bathymetry pertains to coastal areas to a water depth of about 10 meters (20 meters in the Florida Keys and elsewhere where waters are exceptionally clear).

Offshore Bathymetry - For the purpose of this study, offshore bathymetry pertains to areas deeper than 10 meters under water including the Great Lakes.

1.4. 3D Nation Study Process

The 3D Nation Elevation Requirements and Benefits Study process included the following: (1) developing a study questionnaire; (2) outreach and training activities related to the questionnaire; (3) administering the online questionnaire; (4) developing a geodatabase (GDB) to store the study data; (5) conducting validation meetings with each state, federal agency, and non-governmental entity that responded to the questionnaire; (6) collecting cost information and selecting program implementation scenarios; (7) developing tools that were used to analyze study results and evaluate program implementation scenarios using Benefit Cost Analysis (BCA) and Return on Investment (ROI) Analysis; and (8) documenting the study results in this report.

1.5. Study Participation

Study participants were selected by the primary Point of Contact (POC) for the participating federal agencies, state champions, and USGS and NOAA liaisons from among individuals who use elevation data to address their business needs.

A total of 1,352 Mission Critical Activities (MCA) were reported by study respondents from 45 federal agencies, 56 states and territories, and 58 non-governmental organizations (NGO)[1]. The responses are broken down by organization type and geography type, as shown in Table 1. Note that details of the MCAs are provided in Appendix F (federal agencies), Appendix G (state, regional, county, city or other local governments and territories), Appendix H (private entities), and Appendix I (not-for-profit entities and associations).

Table 1. Summary of organizational types

Organization Type	Number of Agencies /Entities	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Percent of MCAs
Federal Agencies and Commissions	45	198	16%	144	17%	129	19%	89	24%	209	15%
Academia	14	14	1%	11	1%	11	2%	6	2%	14	1%
Not-for-profit	10	7	1%	4	0%	6	1%	5	1%	11	1%
Private or Commercial	34	33	3%	21	3%	24	4%	14	4%	44	3%
States including State, Regional, County, Local, or Territory Government	56	1,011	79%	644	77%	489	74%	254	69%	1,074	79%
Tribal Government*	8	9	1%	7	1%	3	0%	2	1%	10	1%
Total		1,272	100%	831	100%	662	100%	370	100%	1,352	100%

* Tribal government numbers are also included in the state totals

1.6. Mission Critical Activities

Study participants were asked to describe in their own words their MCAs. Because the MCAs were self-described and titled, there was a wide variety among the MCA descriptions. Some MCAs were described in terms of the respondent's agency's organization, some in terms of their daily activities. Some MCAs were very broad and encompassed multiple Business Uses and some were quite narrowly defined.

[1] Throughout this report, all references to "non-governmental organizations" refer to not-for-profit organizations, academic institutions, and for-profit companies for which Mission Critical Activity requirements and benefits are documented in Appendixes H and I.

1.6.2. Number of MCAs by Geography Type

Table 2 shows a summary of the MCAs by geography type. Note that a single MCA could include requirements for multiple geography types.

Table 2. Number of MCAs by geography type

Geography Type	Total MCAs	Percent of MCAs
Inland Topography	1,272	94%
Inland Bathymetry	831	61%
Nearshore Bathymetry	662	49%
Offshore Bathymetry	370	27%

Figure 1 shows the spatial distribution of the MCA areas of interest.

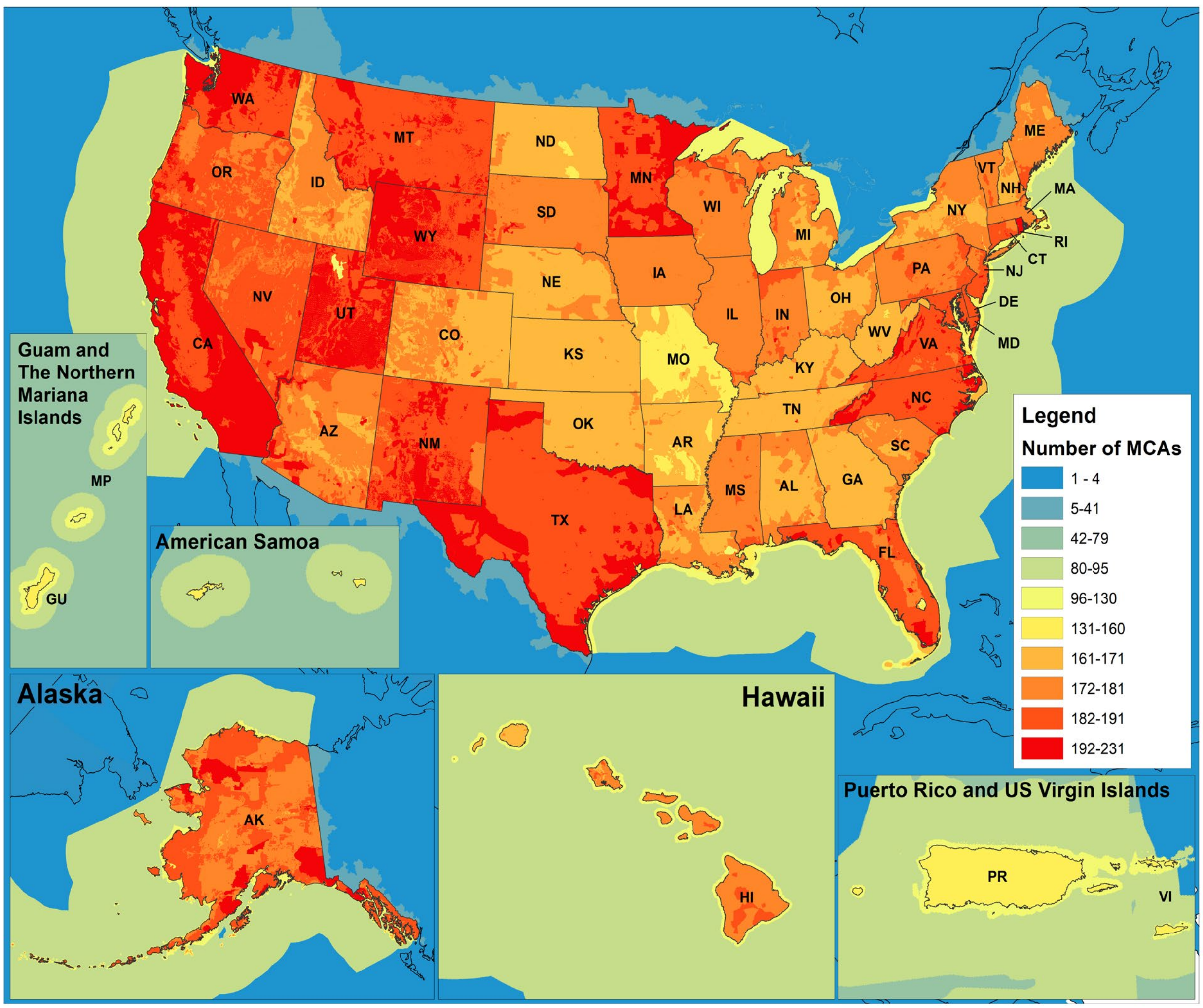

Figure 1. Map showing the spatial distribution of MCA areas of interest

1.6.3. Number of MCAs by Business Use

Table 3 shows the 30 Business Uses and the number of MCAs that listed that Business Use as its primary Business Use. Note that respondents could also list secondary and tertiary Business Uses in their MCA descriptions. Note that details of the MCAs and reported benefits for the Business Uses are provided in Appendix E.

Table 3. Summary of MCAs by primary Business Use

Primary Business Uses	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
BU 01 - Water Supply and Quality	78	6%	68	8%	33	5%	17	5%	81	6%
BU 02 – Riverine Ecosystem Management	43	3%	41	5%	21	3%	7	2%	44	3%
BU 03 - Coastal Zone Management	57	4%	44	5%	64	10%	41	11%	66	5%
BU 04 - Forest Resources Management	50	4%	17	2%	9	1%	0	0%	50	4%
BU 05 – Rangeland Management	17	1%	3	0%	0	0%	0	0%	17	1%
BU 06 - Natural Resources Conservation	64	5%	41	5%	29	4%	17	5%	65	5%
BU 07 - Wildlife and Habitat Management	54	4%	45	5%	36	5%	25	7%	58	4%
BU 08 - Agriculture and Precision Farming	32	3%	15	2%	2	0%	2	1%	33	2%
BU 09 - Fisheries Management and Aquaculture	25	2%	30	4%	34	5%	24	6%	43	3%
BU 10 – Geologic Assessment and Hazard Mitigation	59	5%	32	4%	35	5%	21	6%	61	5%
BU 11 - Geologic Resource Mining and Extraction	24	2%	10	1%	6	1%	7	2%	25	2%

Primary Business Uses	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
BU 12 - Renewable Energy Resources	41	3%	16	2%	20	3%	18	5%	44	3%
BU 13 - Oil and Gas Resources	22	2%	12	1%	10	2%	8	2%	23	2%
BU 14 - Cultural Resources Preservation and Management	47	4%	28	3%	26	4%	17	5%	47	3%
BU 15 - Flood Risk Management	102	8%	73	9%	45	7%	21	6%	102	8%
BU 16 - Sea Level Rise and Subsidence	38	3%	27	3%	34	5%	16	4%	38	3%
BU 17 - Wildfire Management, Planning, and Response	31	2%	6	1%	2	0%	1	0%	31	2%
BU 18 - Homeland Security, Law Enforcement, Disaster Response, and Emergency Management	60	5%	41	5%	29	4%	15	4%	60	4%
BU 19 – Land Navigation and Safety	41	3%	24	3%	14	2%	4	1%	41	3%
BU 20 - Marine and Riverine Navigation and Safety	27	2%	40	5%	45	7%	33	9%	51	4%
BU 21 – Aviation Navigation and Safety	31	2%	9	1%	9	1%	4	1%	31	2%
BU 22 - Infrastructure and Construction Management	94	7%	68	8%	43	6%	11	3%	96	7%

Primary Business Uses	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
BU 23 - Urban and Regional Planning	77	6%	41	5%	29	4%	8	2%	77	6%
BU 24 - Health and Human Services	13	1%	6	1%	4	1%	2	1%	13	1%
BU 25 - Real Estate, Banking, Mortgage, and Insurance	15	1%	3	0%	4	1%	1	0%	15	1%
BU 26 - Education K-12 and Beyond, Basic Research	35	3%	31	4%	26	4%	19	5%	39	3%
BU 27 - Recreation	24	2%	22	3%	14	2%	5	1%	26	2%
BU 28 - Telecommunications	29	2%	9	1%	9	1%	5	1%	30	2%
BU 29 - Military	13	1%	5	1%	6	1%	4	1%	14	1%
BU 30 - Maritime and Land Boundary Management	29	2%	24	3%	24	4%	17	5%	31	2%
Total	1,272	100%	831	100%	662	100%	370	100%	1,352	100%

1.7. Summary of Requirements

Respondents provided detailed information about their requirements for elevation data. Most of the requirements are broken out by geography type (Inland Topography, Inland Bathymetry, Nearshore Bathymetry, and Offshore Bathymetry); however, some responses could apply to any geography. User requirements for Quality Level (QL) and update frequency directly informed the BCAs. Those results are highlighted in this section. The detailed requirements are provided in the body of the report in the Summary of Requirements section.

1.7.1. Inland Topography Quality Level and Update Frequency Requirements

Figure 2 depicts the Quality Level requirements for Inland Topography. The greatest number of respondents reported a requirement for QL2 data (36%). The next most frequently reported requirement is for QL1 data (30%). Note however, that 60% of respondents require a higher Quality Level than the current 3DEP standard of QL2.

Figure 3 depicts the update frequency requirements for Inland Topography. The greatest number of respondents reported a requirement for 3D inland topographic data to be updated every 4-5 years (44%). The next most frequently reported requirement is for 3D inland topographic data to be updated every 2-3 years (22%). Note that 75% of respondents require an update frequency higher than the 8-year cycle goal currently used for the 3DEP.

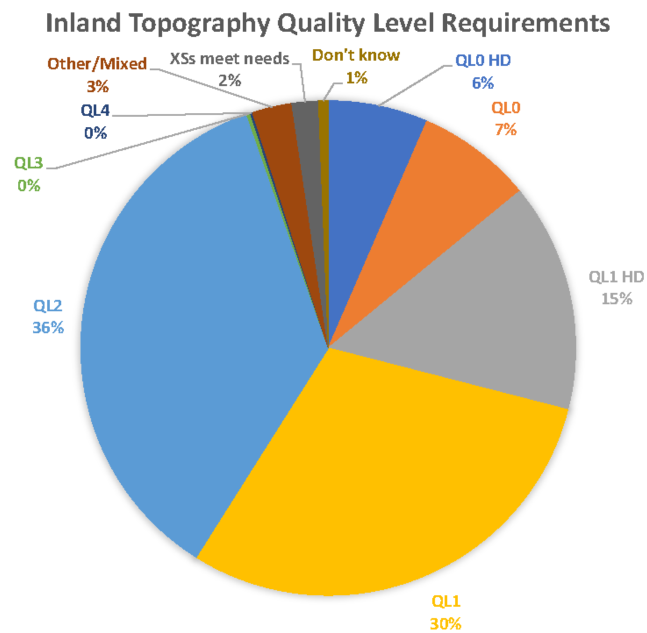

Figure 2. Quality Level requirements for Inland Topography

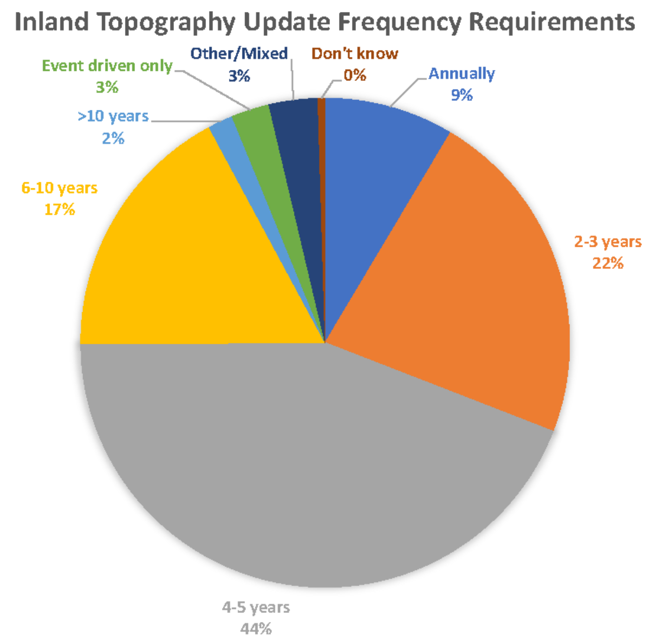

Figure 3. Update frequency requirements for Inland Topography

1.7.3. Inland Bathymetry Quality Level and Update Frequency Requirements

Figure 4 depicts the Quality Level requirements for Inland Bathymetry. The greatest number of respondents reported a requirement for QL0B data (39%). The next most frequently reported requirement is for QL1B data (26%).

Figure 5 depicts the update frequency requirements for Inland Bathymetry. The greatest number of respondents reported a requirement for inland bathymetric data to be updated every 4-5 years (41%). The next most frequently reported requirement is for inland bathymetric data to be updated every 6-10 years (26%).

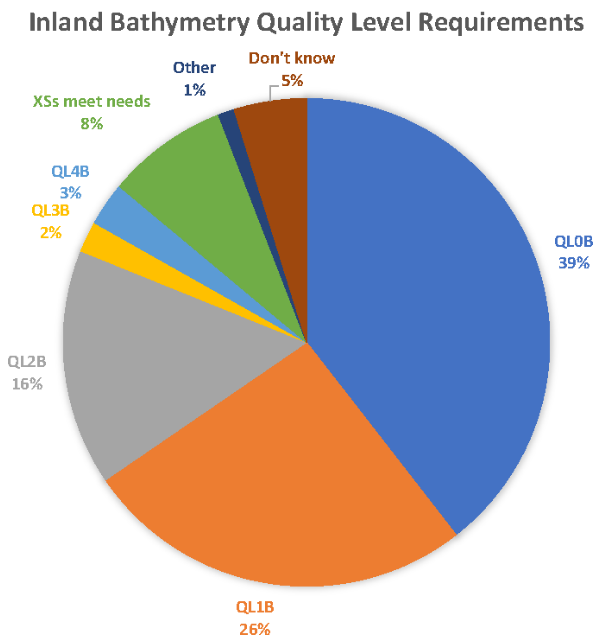

Figure 4. Quality Level requirements for Inland Bathymetry

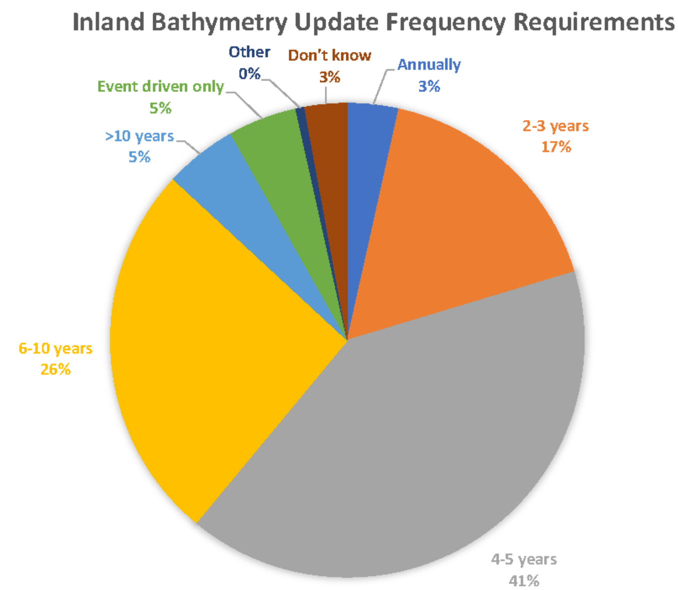

Figure 5. Update frequency requirements for Inland Bathymetry

1.7.5. Nearshore Bathymetry Quality Level and Update Frequency Requirements

Figure 6 depicts the Quality Level requirements for Nearshore Bathymetry. The greatest number of respondents (34%) reported a requirement for QL0B data. The next most frequently reported requirement is for QL1B data (24%).

Figure 7 depicts the update frequency requirements for Nearshore Bathymetry. The greatest number of respondents (36%) reported a requirement for nearshore bathymetric data to be updated every 4-5 years. The next most frequently reported requirement is for nearshore bathymetric data to be updated every 2-3 years (29%).

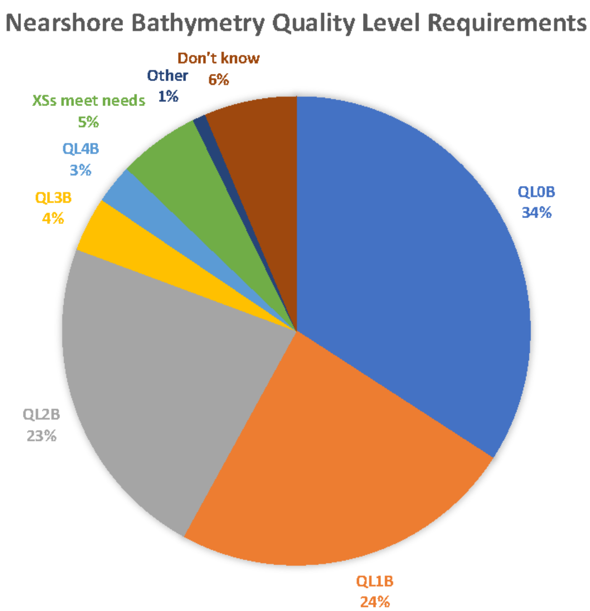

Figure 6. Quality Level requirements for Nearshore Bathymetry

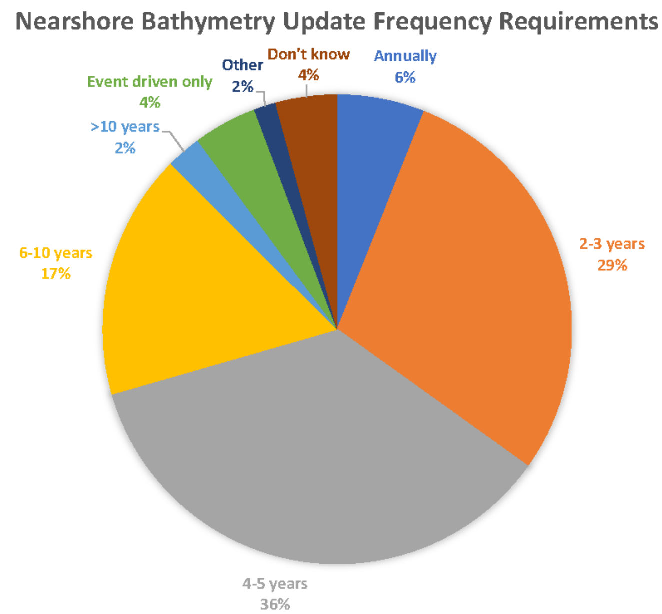

Figure 7. Update frequency requirements for Nearshore Bathymetry

1.7.7. Offshore Bathymetry Quality Level and Update Frequency Requirements

Figure 8 depicts the Quality Level requirements for Offshore Bathymetry. The greatest number of respondents (20%) reported a requirement for Order 1a data. However, an equal number of respondents said, “I don’t know,” while another 19% reported a requirement for Special Order data. In total, 38% reported a requirement for Order 1, 1a, or 1b data.

Figure 9 depicts the update frequency requirements for Offshore Bathymetry. The greatest number of respondents (27%) reported a requirement for offshore bathymetric data to be updated every 4-5 years. The next most frequently reported requirement is for offshore bathymetric data to be updated every 2-3 years (24%), with an equal number (24%) reporting a requirement for offshore bathymetric data to be updated every 6-10 years.

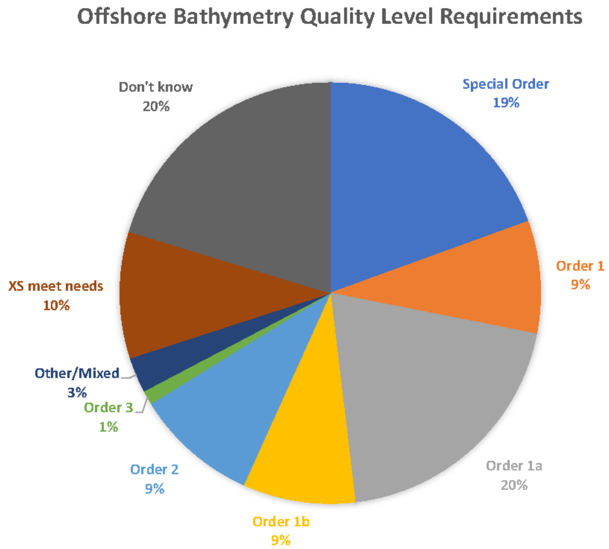

Figure 8. Quality Level requirements for Offshore Bathymetry

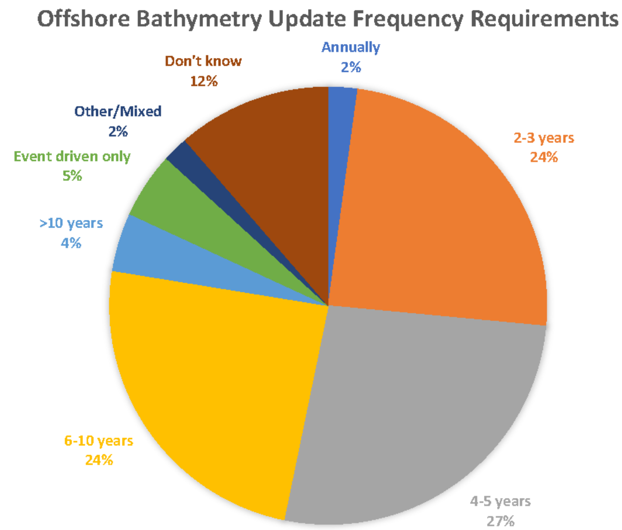

Figure 9. Update frequency requirements for Offshore Bathymetry

1.8. Summary of Benefits

Respondents were asked to provide both a qualitative and a quantitative estimate of the future benefits their program would gain from having their requirements for 3D elevation data met.

Respondents were asked to estimate their future annual benefits for the following categories:

- **Operational Benefits**, which include time savings, cost savings or cost reductions (e.g., savings on purchases), increased revenues to the organization, and mission-driven performance improvements. Respondents were asked to estimate both qualitative and quantitative (dollar) future annual benefits in either hours (annual or monthly) or as dollars.
- **Customer Service Benefits**, which include value added to products or services, improved response or timeliness, and improved customer experience. Respondents were asked to estimate both qualitative and quantitative (dollar) future annual benefits in either hours (annual or monthly) or as dollars.

- **Societal Benefits**, which include education or outreach; environmental benefits; and public safety, including life and property. Respondents were asked to provide a qualitative estimate of future annual benefits their program as “Major,” “Moderate,” “Minor,” “None,” or “Don’t know.”

Table 4 summarizes the reported future annual dollar benefits by geography type.

Table 4. Summary of reported future annual dollar benefits by geography type

Geography Type	Total Reported Future Annual Benefits
Inland Topography	$9.99B
Inland Bathymetry	$0.86B
Nearshore Bathymetry	$2.55B
Offshore bathymetry	$0.16B
Total	$13.56B

Table 5 summarizes the reported future annual dollar benefits by organization type.

Table 5. Summary of reported future annual dollar benefits by organization type

Organization Type	Total Reported Future Annual Benefits
Federal agencies	$5.84B
State, regional, county, local, and tribal governments	$7.68B
Not-for-profit and private entities	$0.04B
Total	$13.56B

Table 6 summarizes the reported future annual dollar benefits by geography type and Quality Level. Note that maps showing reported future annual dollar benefits by geography type, Quality Level, and update frequency are provided in Appendix J.

Table 6. Reported future annual dollar benefits by geography type and Quality Level

Inland Topography Quality Level	Total Reported Future Annual Dollar Benefits	Inland Bathymetry Quality Level	Total Reported Future Annual Dollar Benefits	Nearshore Bathymetry Quality Level	Total Reported Future Annual Dollar Benefits	Offshore Bathymetry Quality Level	Total Reported Future Annual Dollar Benefits
QL0HD	$2,246,804,952	QL0B	$194,456,321	QL0B	$2,274,720,161	Special Order	$13,509,642
QL0	$1,603,922,384	QL1B	$306,432,390	QL1B	$49,177,017	Order 1	$43,164,076
QL1HD	$659,745,643	QL2B	$210,941,446	QL2B	$127,383,522	Order 1a	$26,717,440
QL1	$1,851,264,690	QL3B	$4,245,733	QL3B	$747,540	Order 1b	$59,159,080
QL2	$3,364,564,846	QL4B	$6,818,367	QL4B	$8,219,074	Order 2	$10,543,682
Cross sections	$262,811,330	Cross sections	$137,877,187	Cross sections	$89,756,778	Cross sections	$10,050,449
I don't know	$23,114	I don't know	$1,733,036	I don't know	$765,307	I don't know	$784,554
Total	$9,989,136,958		$862,504,479		$2,550,769,398		$163,928,922

Table 7 summarizes the reported future annual dollar benefits by Business Use.

Table 7. Summary of reported future annual dollar benefits by Business Use

Business Use	Total Reported Future Annual Benefits
BU 01 - Water Supply and Quality	$0.30B
BU 02 – Riverine Ecosystem Management	$0.07B
BU 03 - Coastal Zone Management	$4.35B
BU 04 - Forest Resources Management	$0.04B
BU 05 – Rangeland Management	$0.00B
BU 06 - Natural Resources Conservation	$0.72B
BU 07 - Wildlife and Habitat Management	$0.04B
BU 08 - Agriculture and Precision Farming	$0.01B
BU 09 - Fisheries Management and Aquaculture	$0.04B
BU 10 – Geologic Assessment and Hazard Mitigation	$0.87B
BU 11 - Geologic Resource Mining and Extraction	$0.03B
BU 12 - Renewable Energy Resources	$0.01B

Business Use	Total Reported Future Annual Benefits
BU 13 - Oil and Gas Resources	$0.02B
BU 14 - Cultural Resources Preservation and Management	$0.00B
BU 15 - Flood Risk Management	$1.66B
BU 16 - Sea Level Rise and Subsidence	$0.32B
BU 17 - Wildfire Management, Planning, and Response	$0.03B
BU 18 - Homeland Security, Law Enforcement, Disaster Response, and Emergency Management	$2.15B
BU 19 – Land Navigation and Safety	$0.05B
BU 20 - Marine and Riverine Navigation and Safety	$0.58B
BU 21 – Aviation Navigation and Safety	$0.07B
BU 22 - Infrastructure and Construction Management	$1.17B
BU 23 - Urban and Regional Planning	$0.82B
BU 24 - Health and Human Services	$0.00B
BU 25 - Real Estate, Banking, Mortgage, and Insurance	$0.04B
BU 26 - Education K-12 and Beyond, Basic Research	$0.08B
BU 27 - Recreation	$0.01B
BU 28 - Telecommunications	$0.00B
BU 29 - Military	$0.01B
BU 30 - Maritime and Land Boundary Management	$0.08B
Total	$13.56B

1.9. Benefit Cost Analyses

Three widely used methods for performing BCA are: (1) Net Benefits where costs are subtracted from the benefits (Net Benefits = benefits minus costs); (2) Benefit/Cost Ratio (BCR) where the benefits are divided by the costs (BCR = benefits/costs); and (3) (ROI where the net benefits are divided by the costs and expressed as a percentage (ROI = net benefits/cost ÷ 100). All three methods were calculated for the 3D Nation Study Benefit Cost Analyses.

Benefit/Cost Ratios prioritize lower costs but do not necessarily provide the highest benefits. Net benefits prioritize benefits but those scenarios with higher net benefits may cost more.

Benefit Cost Analyses were run for a range of nationwide uniform Quality Levels and update frequencies for each of the geography types as well as some combinations of Quality Levels and update frequencies that varied spatially. A summary of the results of the analyses are provided in the section titled "Benefit Cost Results." The detailed results of the analyses are provided in Appendix K.

Cost information used in the BCRs and ROI analyses was provided by USGS and NOAA. Estimated average costs were provided for the acquisition of topographic lidar for Inland Topography, topobathymetric lidar and sonar for Inland Bathymetry, topobathymetric lidar for Nearshore Bathymetry, and sonar for Offshore Bathymetry.

Recognizing that benefits are unrealized if users do not receive the Quality Level and update frequency required, Dewberry applied a procedure for degrading annual dollar benefits with reduced *value multipliers* explained below.

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

1.10. Benefit Cost Analysis Results

This section summarizes the results of the BCAs that were run for the 3D Nation Study. Further details are provided in the body of the report and in Appendix K.

1.10.1. Inland Topography

Nationwide BCAs were performed on the 25 uniform Quality Level and update frequency combinations for Inland Topography. In addition, analyses were requested for several other combinations of Quality Levels and update frequencies.

All of the scenarios evaluated provide a positive BCR and positive net benefits. Based on the highest BCR, the scenarios that cost the least because they either deliver lower quality data or the costs are spread over a longer period (e.g., update frequencies of >10 years) rank highest. Thus, QL2 data with an update frequency of >10 years provides the highest BCR. While this might be the most cost-effective future program, it is actually not better than the current 3DEP program and may not be a wise choice for 3DEP to pursue.

Based on the highest net benefits, the scenarios that provide the highest benefits would deliver the highest quality of data or are refreshed most frequently. QL0 high-density (HD) data updated every 4-5 years was documented to provide the highest net benefits. However, a national program for QL0HD data may not prove to be affordable or achievable in the long run. Therefore, an option in the middle that balances the BCR and net benefits may be the best option.

1.10.2. Inland Bathymetry

QL2B topobathymetric lidar and QL0B sonar were analyzed for Inland Bathymetry. It was assumed that all lakes and ponds will require sonar collection as will some rivers. Different combinations of the areas used to calculate the acquisition costs were used for the Inland Bathymetry BCAs.

The three scenarios with update frequencies greater than 2-3 years all were documented to provide a positive BCR and net benefits. Based on both the highest BCR and the highest net benefits, the scenarios where the costs are spread over a longer period rank highest. Since only one Quality Level was analyzed, only the update frequency influenced the results.

1.10.3. Nearshore Bathymetry

The primary Quality Level analyzed for Nearshore Bathymetry was QL2B because that is what is collected using the current topobathymetric lidar sensors. In addition to nationwide analyses for QL2B at the different update frequencies, a scenario for more frequent updates in and around ports and harbors was analyzed as well as ones that examined only the areas identified as priority areas by the different federal agencies that participated in the IWG-OCM 2021 prioritization survey. A lower cost option using satellite derived bathymetry (SDB) for the depth band of 0-10 meters was also analyzed. Three different satellite imagery sources at differing ground sample distance (GSD) were examined with the assumption of a one-time only collection for each.

All of the scenarios evaluated were documented to provide a positive BCR and net benefits. Based on the highest BCR, the scenarios that cost the least because they either deliver lower quality data (e.g., SDB) or the costs are spread over a longer period (e.g., update frequencies of >10 years) rank highest. The SDB options provide the highest BCR. While this might be the most cost-effective future program, the Quality Level is worse than the current NOAA and Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) topobathymetric collection programs and specification and would not be a wise choice for a national program.

Based on the highest net benefits, the scenarios that provide the highest benefits because they are refreshed most frequently rank the highest. Thus, QL2B data updated annually provides the highest net benefits. While this may provide the highest benefits, annual updates are unlikely to be affordable or achievable in the long run. Therefore, an option in the middle that balances the BCR and net benefits may be the best option.

1.10.4. Offshore Bathymetry

Order 1a and Order 2 hydrographic survey data were analyzed for Offshore Bathymetry. In addition to nationwide analyses for Order 1a with the five different update frequencies, scenarios for update frequencies of 30 years and 100 years were analyzed, and a scenario that represents the NOMEC Strategy was analyzed. Additionally, scenarios for specific depth bands were analyzed, as were scenarios based on NOAA's OCS Hydrographic Health Model (HHM) priorities, which are based on navigational risks, as well as ones that examined only the areas identified as priority areas by the different federal agencies that participated in the IWG-OCM 2021 prioritization survey.

Although industry response on Offshore Bathymetry requirements and benefits was low, contributing to an undercount by study respondents, scenarios that combined Order 1a for waters 10-100 meters deep and Order 2 in waters greater than 100 meters deep were also analyzed for the five different update frequencies. Additionally, scenarios that added unmanned systems (UxS) (i.e., uncrewed surface vessels) as a force multiplier for hydrographic survey missions were examined.

Finally, NOAA was interested in understanding how cost avoidance as a benefit might affect the results as well as what the impacts would be if the islands in the Pacific territories were not included in the acquisitions.

The scenarios that provide a positive BCR and positive net benefits are those that assume cost avoidance as an added benefit, those that combine the Nearshore Bathymetry and Offshore Bathymetry portions of the NOMEC Strategy, and the one that spreads the costs over 100 years.

Based on the highest BCR and the highest net benefits, the scenarios that spread the costs over the longest period ranked highest. The scenario that spreads the costs over 100 years and assumes cost avoidance as a benefit provides the highest BCR . However, that timeline does not meet current Administration goals as outlined in the NOMEC Strategy (i.e., full bottom coverage to the Exclusive Economic Zone (EEZ) of the United States by 2040). While this may be the most cost-effective future program direction, it may not be the wisest choice for a national program that seeks to improve the mapping, exploration and characterization of the EEZ for more efficient permitting of ocean exploration, mapping, and research activities.

All of the NOMEC Strategy scenarios where Nearshore and Offshore Bathymetry areas are combined provide a positive BCR and net benefits. Based on the highest BCR and the highest net benefit, the two NOMEC Strategy scenarios that cost the least because they provide Order 2 data in the deeper waters rank highest.

1.11. Observations and Conclusions

This section provides some high-level observations about the data that were collected during this study and the results of the analyses performed on the data. The observations cover the maturity of current acquisition systems and user familiarity with the resulting data, collaboration among federal agencies and their partners, risks associated with the elevation data collection technologies, and some of the reasons why we believe the benefits of elevation data were undercounted by the study respondents. Additionally, there are several steps that could be taken to fill what we perceive as gaps in future annual benefits estimates. These include additional individual outreach to known users of elevation data in underrepresented industries as well as mining previously conducted economic valuation studies to estimate the percent of various economic sectors or programs that rely on elevation data and their value.

1.11.1. Acquisition

The following observations are provided regarding the maturity of acquisition systems and programs as well as user familiarity with the use of elevation data to support their programs.

1.11.1.2. Inland Topography

- The 3DEP has almost completed its first pass of elevation data collection for the Nation with QL5 Interferometric Synthetic Aperture Radar (IfSAR or InSAR) in Alaska and QL2 lidar elsewhere in the U.S.

- The 3DEP data acquisition technologies, processes, and products are mature. IfSAR and lidar acquisition costs are well understood.

- Many users have developed robust systems for using lidar data and thus could estimate their future annual dollar benefits for enhanced elevation data. However, many other users still don't know what to do with the data to best serve their programs and could not estimate their benefits.

1.11.1.3. Inland Bathymetry

- There has been very little inland bathymetry collected and made publicly available to date. USGS has collected data for a few pilot projects and U.S. Army Corps of Engineers (USACE) has collected data in some navigable waters, but overall, very little data are available. 17% of the respondents said the data they need are not available; 26% report using navigation charts as the source of inland bathymetry rather than a digital elevation model (DEM).

- While topobathymetric lidar collection technology and processes are well understood for coastal areas, they have not been tested in many of the challenging inland river or lake environments. The understanding of how well topobathymetric lidar will work in the varying conditions of water clarity, turbidity, and depth in the inland waters of the U.S. is not as advanced as it is for coastal areas. And there are many challenging areas where other conditions such as rapids, overhanging vegetation, steep banks, and inaccessible surrounding terrain could make sonar collections difficult and expensive, even using unmanned systems.

1.11.1.4. Nearshore Bathymetry

- NOAA, USACE (via the JALBTCX acquisition program), and USGS have been collecting nearshore bathymetric data for many years. Much of the nearshore areas of the U.S. have at least one collection of topobathymetric data available. However, the coastal zone by nature is a very changeable area due to storms, wave action, erosion and other natural and manmade impacts. In addition, the existing data may be of mixed Quality Levels and/or age. Additionally, the data may have been collected to slightly different specifications depending on which agency did the acquisition and for what use the data were intended.

- The topobathymetric lidar data acquisition technologies, processes, and products are mature and the acquisition costs are well understood. The topobathymetric sensors keep improving so data quality should continue to improve, and costs may continue to go down.

- Due to varying environmental conditions there will be unavoidable data voids where waters are not clear, in the "white ribbon" where the surf is high, etc. However, coordinating acquisition windows to tide levels and water clarity (i.e., using NOAA's Water Clarity Climatology K_d Viewer) can reduce the data voids.

1.11.1.5. Offshore Bathymetry

- NOAA has been acquiring hydrographic data for many years using multi-beam echo sounders (MBES) or single-beam echo sounders (SBES) and supplemented with side scan sonar and backscatter. However, this zone is also very changeable, and the current pace of collection does not meet the Nation's needs.

- Private industry collects offshore bathymetry for its own needs as well (e.g., for oil and gas exploration or extraction, offshore wind farm siting, etc.) but typically do not share the data that are acquired. NOAA has entered into a pilot Memorandum of Agreement with Orsted (offshore wind energy) to explore a data sharing model, and has also developed a data licensing policy to facilitate sharing.

- Several private companies are focusing on developing UxSs for use as stand-alone collection systems or in tandem with a crewed vessel. It is expected that may boost acquisitions at significantly lower costs if the need for crewed vessels and their associated costs can be reduced or eliminated.

- Crowd-sourced bathymetry[2] data whereby commercial or private vessels collect and submit bathymetry while traversing their normal day-to-day travel routes has some potential to fill out collection areas. However, the data normalization and quality control (QC) requirements may be significant. Additionally, predicting where data will be collected for project planning is likely to be very difficult.

- SDB is useful for general mapping purposes only. The data have coarse resolution (typically 2m) compared with fine resolution (cm) from topobathymetric lidar and sonar; SDB is totally dependent on water clarity and the quality of the satellite imagery; SDB data are not Safety of Life at Sea (SOLAS) compliant; SDB data cannot be used where safety of maritime navigation is an issue; and there are no official International Hydrographic Organization (IHO) standards for SDB.

- Crewed hydrographic survey vessels have been the mainstay for collecting bathymetry for many decades. The main advantages are that traditional sonar mapping technologies and

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[2] Soon almost anyone's boat will be able to map the lakes - Great Lakes Bottom Mapping Working Group (glos.org)

platforms are tried, proven, and reliable. The main disadvantage is the relative high cost of such surveys. Fortunately, innovative and lower-cost solutions are now available to execute the NOMEC Strategy.

1.11.2. Collaboration

The following observations are provided regarding the importance of collaboration to a national elevation program.

- Continued coordination between federal agencies regarding data acquisitions and funding partnerships is critical to reducing the possibility of duplication of effort as well as costs for mobilization and demobilization. Tools such as the U.S. Federal Mapping Coordination site, currently managed by NOAA, can be used for federal agencies and their partners to collaborate on mapping data acquisition.

- The 3DEP Broad Agency Announcement (BAA) proposal process has been successfully used by USGS to identify partners for topographic data collection projects. A similar process should be considered to identify partners for collection of elevation data in other geographies.

- Currently, topobathymetric lidar contractors fly to different standards and specifications when acquiring data for JALBTCX, the NOAA/National Geodetic Survey (NGS) Remote Sensing Division, or the USGS National Geospatial Program. These agencies should continue to bring their differing specifications into alignment which should improve future interoperability across collection areas.

1.11.3. Technology Risks

Each of the technologies for collecting elevation data evaluated in Appendix L is subject to risks that may affect their ability to capture elevation data accurately. Most of these risks are associated with environmental conditions (e.g., clouds, fog, turbidity of water). Careful planning of collection missions can overcome some. Others may be beyond human control and may result in the need for repeat acquisition missions or acquisition with an alternate technology. The following are major risks to technologies for elevation data acquisition.

- The major risk to all optical technologies is caused by clouds or fog which impact topographic and topobathymetric lidar, Structure from Motion (SfM), and SDB.

- Topobathymetric lidar technology risks include water depth, flow rate, turbidity, and bottom reflectivity. A hybrid approach for collecting inland bathymetry employing topobathymetric lidar for shallower and clearer areas, MBES for deeper channels), and SBES using a UxS in areas that are too shallow for MBES and too turbid for lidar. To achieve a complete bottom surface model, the topographic lidar, topobathymetric lidar, and sonar data then need to be merged in order to fully satisfy objectives of the 3D Nation initiative.

- Turbidity is the single most important consideration for success of a topobathymetric lidar project. Local knowledge of turbidity and its drivers in the survey area is key to scheduling a topobathymetric lidar survey with the greatest chance of success. Turbidity can be highly variable depending on the day or the season. Similarly, water turbidity is the major risk to success of SDB.

- For safety purposes, MBES surveys are normally performed in waters deeper than the Navigational Area Limit Line (NALL); some systems are better than others for waters shallower than the NALL, but they too have risks that the platform could run aground.

1.11.4. Undercounted Benefits

The following observations are provided regarding possible reasons why dollar benefits are underreported for this study.

- Federal agencies find it hard to estimate dollar benefits in general.

- Private industry is hesitant to reveal costs and business practices.

- Respondents were hesitant to estimate benefits from data they do not have access to or use regularly. 3DEP data are better known and understood than bathymetry. Many users have developed robust systems for using topographic and topobathymetric lidar data and thus could estimate their future annual dollar benefits for enhanced elevation data. However, other users still don't know what to do with the data to best serve their programs and could not estimate their benefits. Additionally, there is not much availability of inland bathymetric data yet and we believe many users could not envision how to use such data or what the benefits of having such data would be to their programs.

- Federal agency POCs nominated study participants from their agencies. The state champions nominated state participants. Private industry participants were nominated by the USGS and NOAA study team and/or were invited as members of an association that represents an industry with a need for elevation data. Study participants may not have been as representative of the bathymetry community as the topography community due to prior experience with the NEEA topographic study.

- In our B/C model, dollar benefits are assigned only to the primary Business Use. The secondary and tertiary Business Uses do not get any dollar benefits assigned to them. Many respondents had a hard time choosing just one Business Use as primary; thus we believe many Business Uses are underrepresented.

- Of the 24,000+ private sector engineering firms and 16,000+ private sector land surveying firms in the U.S., only one small engineering firm responded to the 3D Nation questionnaire. That one engineering firm indicated millions of dollars in annual savings from the availability of accurate and authoritative elevation data in the public domain routinely used for engineering studies and engineering design services and topographic surveys mandated by local zoning and permitting regulations. NOAA and USGS had no way to contact 40,000 engineering and surveying companies to document their elevation data requirements and benefits, and it would have been impractical to do so; however, if more of the 24,000 other engineering firms and 16,000 land survey firms had similarly responded, the annual benefits of public domain elevation data would have been billions of dollars higher, spread across most of the 30 Business Uses.

- For maritime navigation and safety, there are many thousands of recreational boaters, commercial fishing vessels, oil tankers, cargo carriers, cruise ships, tugboats, etc. that rely upon inland, nearshore and offshore bathymetry for navigation purposes and to maintain under keel clearance while avoiding rocks, shoals and other obstacles. A single ship running aground incurs tremendous costs. America's seaports move trillion of dollars' worth of international cargo, relying on accurate bathymetric data for navigation safety; however, the study team, including NOAA and USGS, was unable to identify any organization that could represent the diverse maritime industry and estimate the value of bathymetric data needed for maritime navigation and safety. Individual companies invited to the study were hesitant to state benefits or were nonresponsive. For this reason, benefits for inland, nearshore and offshore bathymetry are severely undercounted in this study.

- Other ocean industries such as oil and gas, wind energy, mineral extraction, etc. are also underrepresented in the study and those requirements and benefits are undercounted in this study.

- Many respondents were able to assign qualitative benefits (i.e., Major/Moderate/Minor) but were unable to assign a dollar benefit to the availability of elevation data. If we could assign a dollar benefit to "Major" benefits, the dollar benefits would increase significantly.

  For instance, if the hundreds of reported "Major" Operational and Customer Service benefits could be translated into a one percent savings of the total program budgets, this could easily be translated into tens of billions of additional dollars in annual savings. But we do not know the program budgets and have no way of knowing if a one percent savings is appropriate or not.

  We do know that for those reporting "Major" Operational benefits as well as dollar benefits, the value of "Major" benefits ranges from $1.2 to $8.2 million. If the average $4.5 million value of "Major" Operational benefits were applied to the 447 MCAs that reported "Major" Operational benefits but could not estimate any dollar benefits, the total estimated annual dollar benefits could increase by as much as $2 billion.

- We believe that data are missing for several Business Uses for which inland topographic data play a key role. This includes the following industries that either did not participate in the study or were unable to quantify their benefits:
    - Commercial timber
    - Precision agriculture
    - Fish and seafood aquaculture
    - Mining
    - Wind energy
    - Oil and gas
    - Motor vehicle manufacturers
    - Shipping, boating, fishing, and cruise lines
    - Port and harbor managers
    - Engineering and surveying
    - Real estate, banking, mortgage, and insurance
    - Telecommunications
    - Department of Defense (DoD) contractors

1.11.5. What Else Could be Done?

Several additional steps could be taken to potentially fill what we perceive as gaps in future annual benefits estimates. These include the following.

- Individual outreach could be conducted with targeted private sector representatives of the industries noted above to gather additional potential unreported or underreported benefits.
- NOAA previously conducted numerous valuation studies that could be mined for additional information. This effort could potentially estimate the percent of various economic sectors or programs that rely on elevation data and their value. However, to do this we would need input on the contributions of elevation data to the various sectors or programs. Not all sector or program dollar values can be ascribed to the availability of nationwide digital elevation data.
- In addition to previously conducted economic valuation studies, NOAA developed tools to help coastal managers and others estimate the value of the blue economy as well as intangibles such as ecosystem services. Such tools could be used to help estimate the total value of sectors or programs. We would still need to estimate the contribution of elevation data to the values. These tools include the following.
    - Economics: National Ocean Watch Explorer (ENOW Explorer) which streamlines the task of obtaining and comparing economic data, both county and state, for the six sectors dependent on the ocean and Great Lakes: living resources, marine construction, marine transportation, offshore mineral resources, ship and boat building, and tourism and recreation.

- Coastal County Snapshots which provides a way to better understand county resilience in terms of flood hazards, critical facilities, jobs, businesses, and more. Current snapshot topics include flood exposure, marine economy, total economy, and exposure to sea level rise.
- Quick Report Tool for Socioeconomic Data which provides access to economic and demographic data for multiple coastal jurisdictions.

2. Introduction

The NOAA OCS, USGS, and partner mapping agencies on the 3DEP along with the IWG-OCM are working to improve the technology, systems, data, and services that provide information about 3D elevation data and related applications within the U.S. By learning more about business uses and associated benefits that would be realized from improved 3D elevation data, for both heights and depths, the agencies will be able to prioritize and direct investments that will best serve user needs. This 3D Nation Elevation Requirements and Benefits Study will help federal mapping agencies to develop and refine future program alternatives for enhanced 3D elevation data to meet many federal, state, and other national business needs.

2.1. Study Goals

The goals of this study are to capture inland, nearshore, and offshore topographic and bathymetric elevation data requirements and benefits and understand how those requirements and benefits dovetail in the nearshore coastal zone. This study builds upon the 2012 NEEA by collecting new and updated information on requirements and benefits for high resolution topographic elevation data and identifying requirements for repeat data coverage in the years beyond the planned initial 8-year acquisition program. Furthermore, this study aims to capture the information about the need for, and value of elevation data using a sensor agnostic and technology neutral approach. The information captured in this study was categorized into a set of national Business Uses associated with elevation data. The data were then used to evaluate the benefits of successfully supporting those Business Use requirements within the context of major national mapping programs.

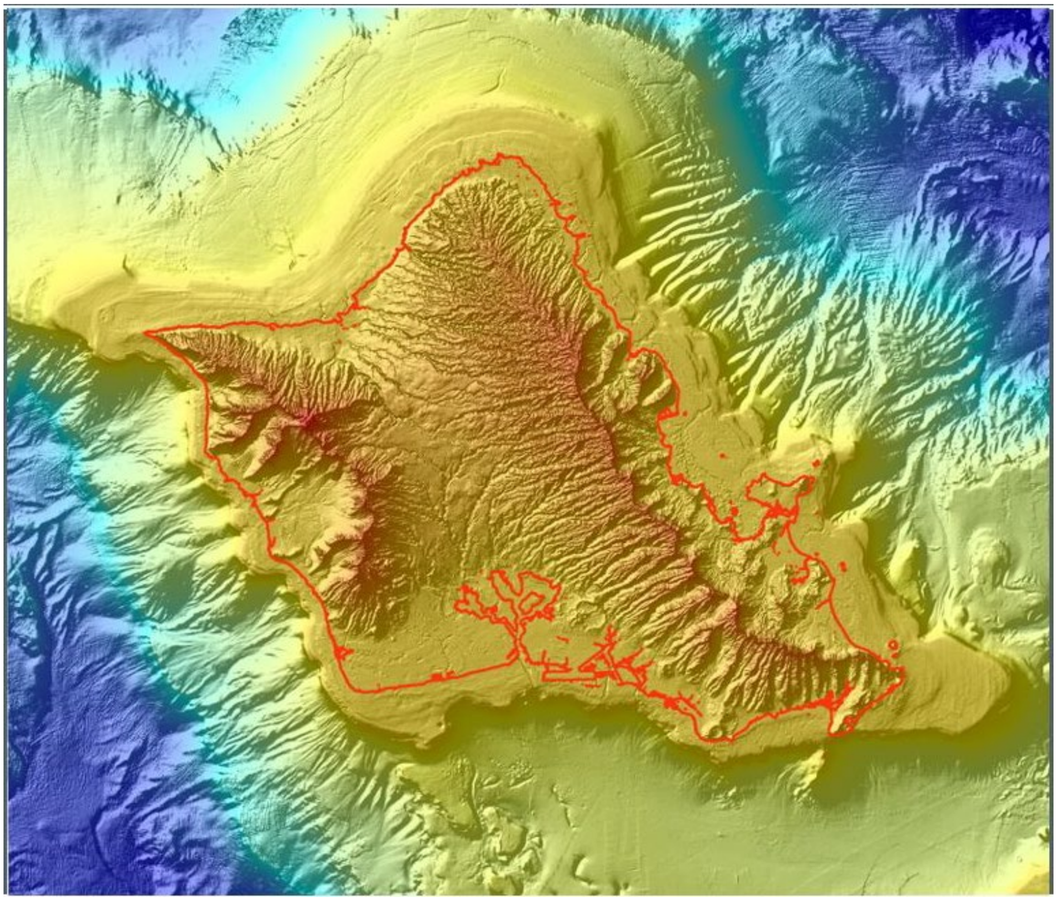


Figure 10. Integrated 1-meter topobathymetric data model for Oahu, Hawaii (USGS CoNED)

2.2. Project Scope

NOAA tasked Dewberry to conduct a study to collect and refine user requirements and to identify associated benefits for 3D elevation data for one or more programs that meet federal, state and other national business uses and needs. The study's findings establish a baseline understanding of national business uses, needs and associated benefits, for 3D elevation data, and can be used to inform the design of an enhanced future elevation acquisition program that balances requirements, benefits, and costs at a national scale.

This project included the following: (1) collection of information from federal agencies; select not-for-profit organizations and private companies; and state, local, and tribal governments about user requirements and benefits of 3D elevation data using an internet-based questionnaire; (2) assessment and validation of the user requirements and associated benefits provided in the questionnaire; (3) consolidation and assessment of MCAs and their 3D elevation data requirements and benefits by Business Use; (4) development of tools that were used to analyze study results and evaluate program implementation scenarios using BCA and ROI Analyses; and (5) documentation of the study results in this final report.

The collection of user requirements and benefits was accomplished through an online questionnaire (Office of Management and Budget [OMB] Control Number 0648-0762) about the use of elevation information. Mission Critical Activities and their associated requirements and benefits were identified by select federal agencies, states, and other NGOs. A study GDB was developed to capture, store, and analyze the original questionnaire data. Summary reports of the questionnaire input were developed and provided to the participating federal agencies and states for use in a validation process involving meetings with the participating agencies and states. The study GDB was used to generate maps and reports documenting the study results as well as to perform BCA and ROI Analyses. The study results are documented in the study GDB and this study report.

3. Background

The following sections provide an overview of several prior studies and initiatives developed by the Government that informed and provided the impetus for this 3D Nation Elevation Requirements and Benefits Study. The prior studies and strategies include the NEEA; the 3DEP initiative; the NCMS 1.0; the National Strategy for Ocean Mapping, Exploring, and Characterizing the NOMEC Strategy; and the USGS 3D National Topography Model Call for Action: 3D Hydrography Program. An overview of the 3D Nation concept is also provided in this section.

3.1. NEEA

The NEEA was conducted by the USGS in 2010 to 2012 to provide technical input and analysis to the Government concerning alternatives and strategies for better meeting the Nation's needs for enhanced elevation data. USGS and other members of the National Digital Elevation Program sponsored this first-ever national assessment to document Business Use requirements for and benefits of national enhanced elevation data that would significantly expand national elevation data availability, quality, and usability. The goal of the assessment was to develop and refine requirements for a national program and to identify program implementation alternatives, costs, and benefits for meeting priority national elevation data needs. The assessment results provided significant evidence that an enhanced national elevation program could provide benefits between $1.2 to $13 billion/year.

Based on the NEEA, the Presidential budget for elevation data collection was increased for the fiscal years of 2014 to 2017. The 3DEP initiative is also based on the results of the NEEA.

3.2. 3DEP

With the results of the NEEA in hand, the USGS National Geospatial Program developed the 3DEP initiative to respond to growing needs for high-quality topographic data and for a wide range of other 3D representations of the Nation's natural and constructed features. The primary goal of 3DEP is to systematically collect 3D elevation data in the form of light detection and ranging (lidar) data over the conterminous U.S. Hawaii, and the U.S. territories, with data acquired over an 8-year period. Completed in 2020, IfSAR data were acquired for all of Alaska, where cloud cover and remote locations preclude the use of lidar in much of the state.

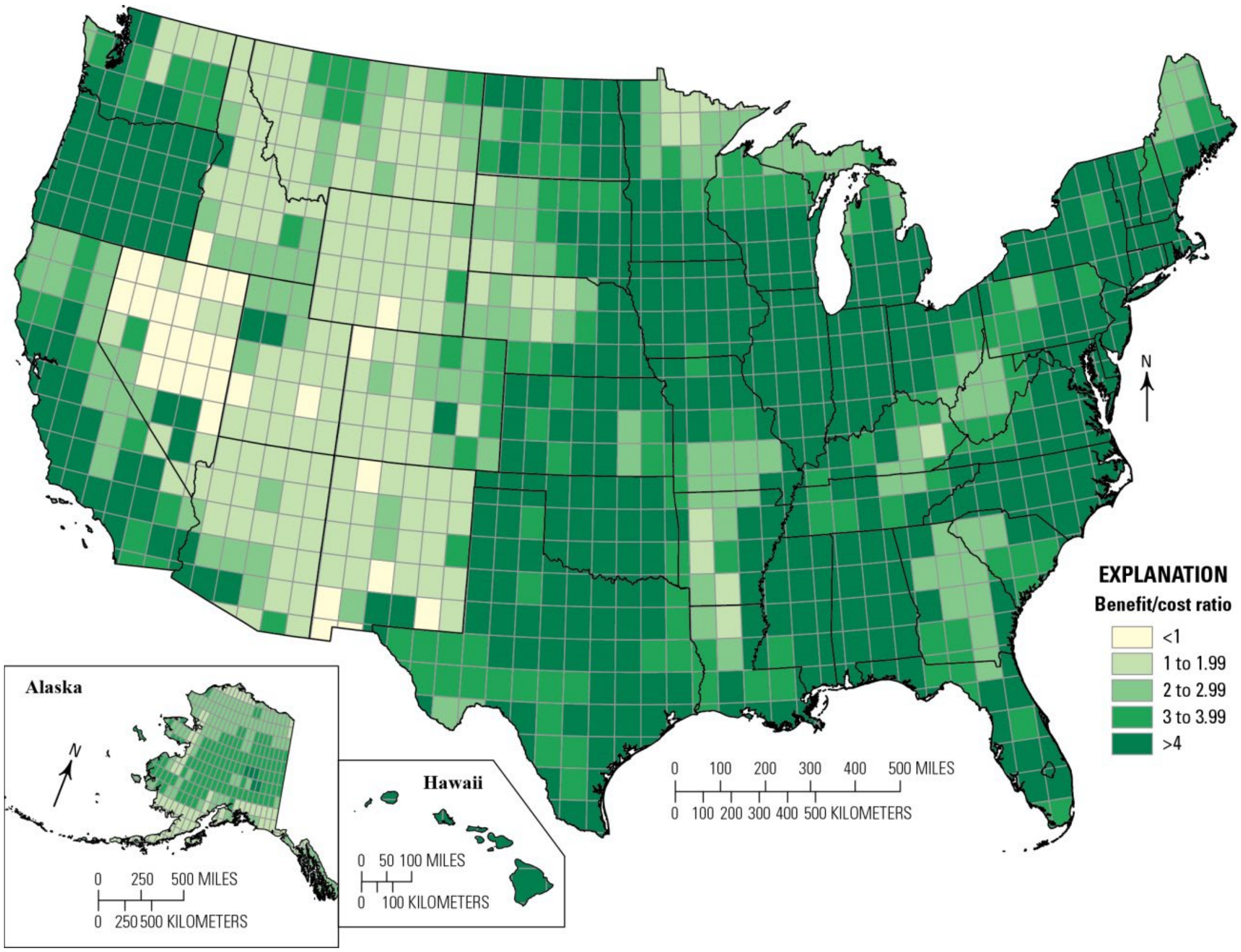


Figure 11. U.S. map depicting NEEA findings on to Cost Ratio for lidar acquisition, based on multiple-use requirements and anticipated applications and outcomes (Sugarbaker et al, 2014)

The 3DEP initiative was based on NEEA results documenting more than 600 business uses across 34 federal agencies, all 50 states, selected local government and tribal offices, and private and nonprofit organizations. A fully funded and implemented 3DEP was estimated to provide more than $690 million annually in new benefits to government entities, the private sector, and citizens.

3DEP provides a framework for collaboration between all levels of government, to leverage the services and expertise of private sector mapping firms that acquire the data, and to create jobs now and in the future. The program is partner-dependent, because no one entity can accomplish nationwide topographic mapping independently. Working together, 3DEP partners have achieved efficiencies and lower costs with comprehensive mapping efforts. When 3D elevation data are available to everyone, new innovations will occur in industries such as forest resource management, alternative energy, agriculture, and others for years to come.

3DEP relies on a BAA proposal process to identify partners for elevation data collection projects. Applicants may contribute funds toward a USGS lidar data acquisition activity via the Geospatial Products and Services Contracts (GPSC) or they may request 3DEP funds toward a lidar data acquisition activity where the requesting partner is the acquiring authority. Federal agencies, state and local governments, tribes, academic institutions and the private sector are eligible to submit proposals.

3.3. National Coastal Mapping Strategy 1.0

The IWG-OCM, tasked by Congress to develop a coastal mapping plan in the Ocean and Coastal Mapping Integration Act of 2009, produced the NCMS 1.0 in 2016. Recognizing the ongoing progress on lidar mapping coordination in the coastal zone, the focus of the first version of the NCMS was on topographic and bathymetric lidar mapping of the U.S. coasts, Great Lakes, territories, and possessions. Future iterations were envisioned to add ocean mapping in the offshore and Outer Continental Shelf regions. The offshore regions will require the use of technologies such as acoustic, aerial photography, and hyperspectral and satellite imagery, to continue building out the U.S. elevation dataset and meet other mapping needs (e.g., bathymetry, nautical charting, habitat assessment, tsunami models, etc.).

The NCMS 1.0 assessed the next steps needed to achieve the vision of the U.S. as a 3D Nation with comprehensive lidar elevation coverage, including whether there is sufficient interest in mapping U.S. coastal areas routinely through the judicious, efficient, and closely-aligned collection of lidar bathymetry and topography. The NCMS 1.0 also recognized the value of the NEEA in understanding the costs and ROI of terrestrial elevation data and recommended a follow-on to the NEEA study that focuses explicitly on the coastal zone and the benefits of incorporating coastal elevation, both onshore and off, more fully into the national elevation enhancement effort. This study, the 3D Elevation Requirements and Benefits Study, is the result of implementing that recommendation.

3.4. National Strategy for Ocean Mapping, Exploring, and Characterizing the U.S. Exclusive Economic Zone

After the NCMS 1.0 was finalized, the 2019 Presidential Memorandum titled "Ocean Mapping of the United States Exclusive Economic Zone and the Shoreline and Nearshore of Alaska" was issued. The Presidential Memorandum included three directives and an interagency framework for how to implement and execute them: Section 2 directs preparation of a national strategy for mapping, exploring, and characterizing the EEZ of the U.S.; Section 3 directs preparation of a strategy for mapping the Arctic and Sub-Arctic Shoreline and Nearshore of Alaska; and Section 4 directs preparation of recommendations for efficient permitting of ocean exploration, mapping, and research activities.

Pursuant to Section 2 of the Presidential Memorandum, the "National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone" (NOMEC Strategy) was released on June 9, 2020. The NOMEC Strategy proposes ambitious goals to completely map the seafloor within the outer boundary of the EEZ; explore and characterize priority areas; and leverage the expertise and resources of multi-sector partnerships. Deploying new and emerging science and technologies at scale - and doing so in partnership with the private sector, academia, and NGOs - is essential to the NOMEC Strategy's success.

The NOMEC Strategy advances five goals, each supported by strategic objectives that incorporate high-level actions, to accomplish the task of mapping, exploring, and characterizing the EEZ. These are:

- Goal 1: Coordinate Interagency Efforts and Resources to Map, Explore, and Characterize the EEZ
- Goal 2: Map the EEZ
- Goal 3: Explore and Characterize Priority Areas of the EEZ
- Goal 4: Develop and Mature New and Emerging Science and Technologies to Map, Explore, and Characterize the EEZ
- Goal 5: Build Partnerships to Map, Explore, and Characterize the EEZ

3.5. NOAA Bathymetry Assessments

NOAA conducted several assessments of available hydrographic survey and bathymetry data. Additionally, a prioritization study was conducted in 2021 to identify priority areas for updated ocean mapping, including bathymetry. Several of these assessments are discussed in this section. These assessments also informed the BCAs performed for this study.

3.5.1. Hydrographic Health Model

NOAA provides nautical charts and other products for the safe navigation of all mariners and maritime commerce for 3.4 million square nautical miles (SNM) of U.S. waters. Updates to these nautical charts are, in part, accomplished by conducting hydrographic surveys that measure and describe the physical features of the seafloor in a body of water. However, due to the vast extent of U.S. waters and limited time and hydrographic surveying resources, U.S. waters must be prioritized for hydrographic survey to maximize efficiency.

The Hydrographic Health Model is a risk-based model that accounts for navigational risks, including both the likelihood of a risk (e.g., traffic density, known hazards to navigation, reported ship groundings, etc.) and the consequence of a risk (proximity to search and rescue stations, proximity to reefs or marine sanctuaries, etc.). The model also considers the necessary quality of data to support modern traffic relative to what is currently available, given the seafloor changes over time. Seafloor changeability accounts for the frequency of storms, current speed, and accumulation of marine debris, where the quality of data in highly changeable areas decreases faster than the quality of data in less changeable areas. Using historic knowledge of seafloor changeability, the model can also approximate the future quality of survey data and assess how often an area needs resurveying.

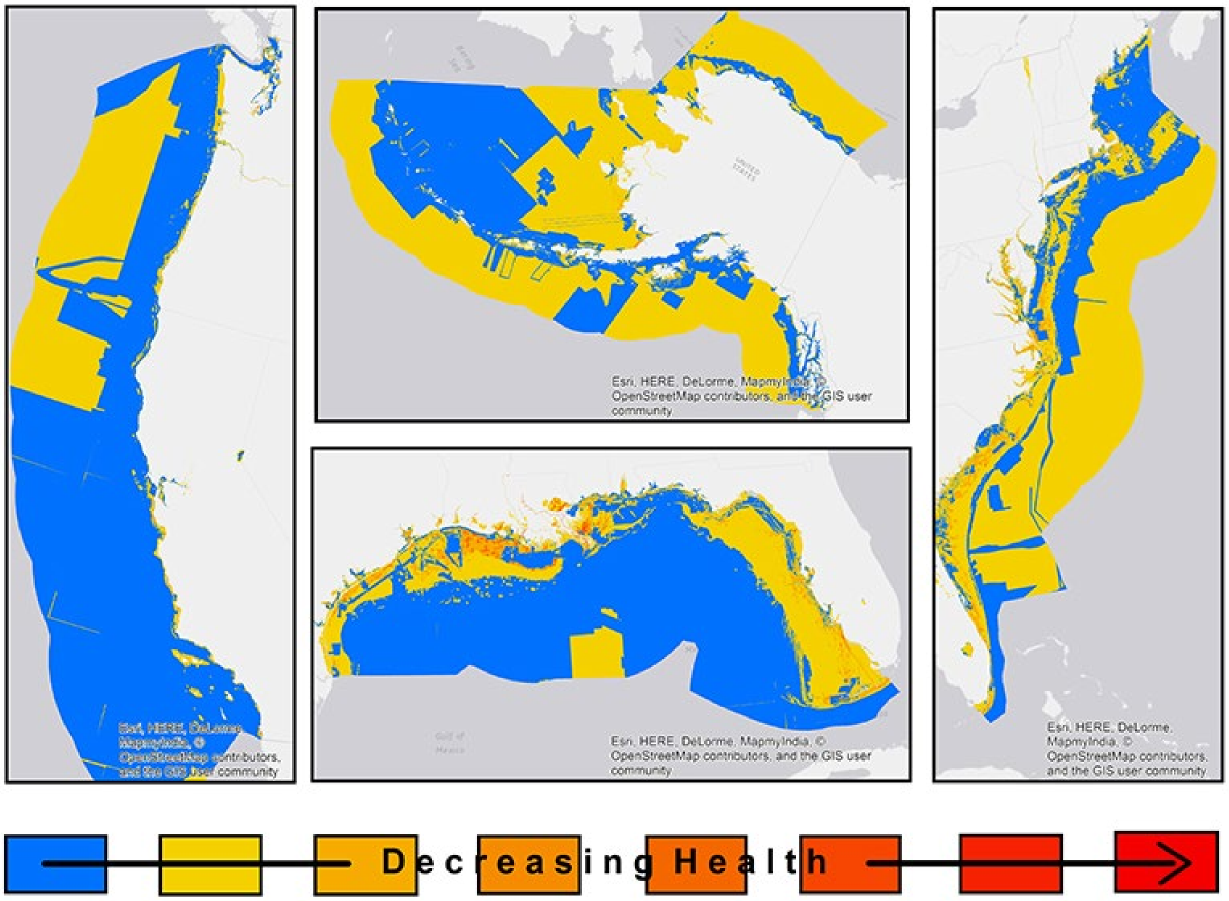
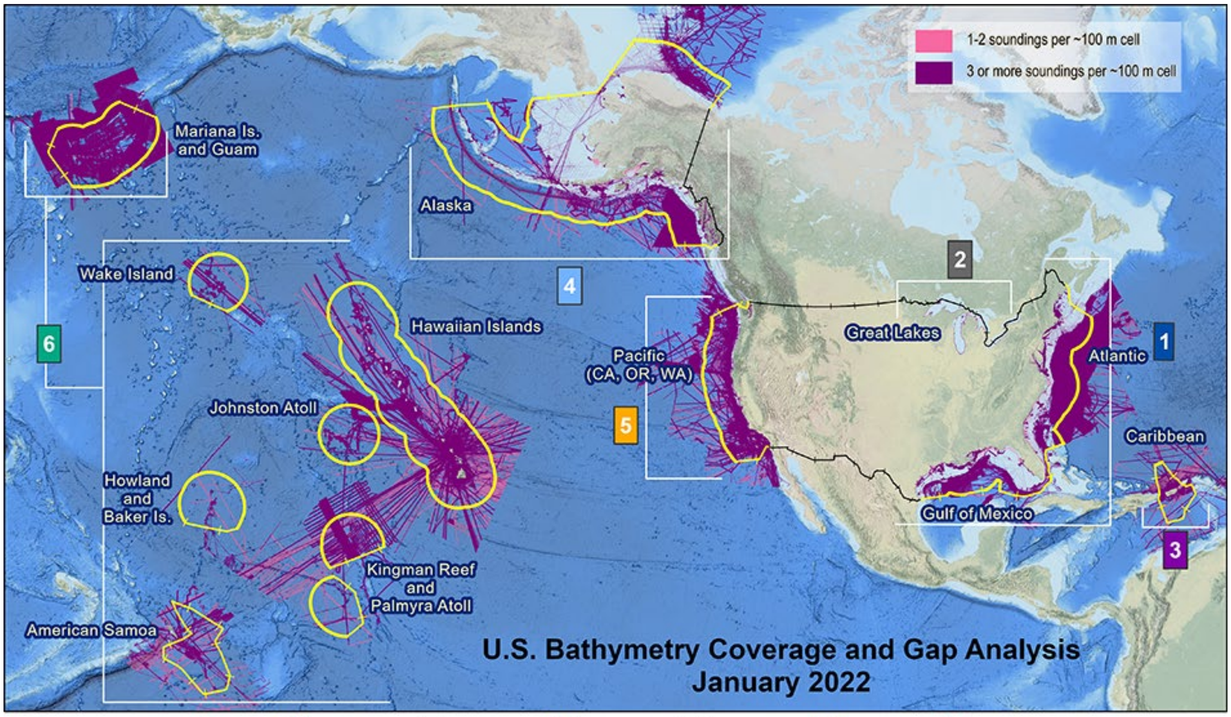


Figure 12. Hydrographic Health Model. Image source: NOAA

3.5.2. Bathymetry Gap Analysis

To inform the implementation plan for the NOMEC Strategy, NOAA undertook an analysis of publicly accessible bathymetric data holdings within U.S. coastal, ocean, and Great Lakes waters to the outer limit of the EEZ. The analysis looked at all modern (post 1960) bathymetric data holdings at NOAA's National Centers for Environmental Information (NCEI) and Office for Coastal Management (OCM). Actual soundings of multi-beam data (raw and processed), single-beam data (>1960), hydrographic surveys (>1960), bathymetric lidar, and crowdsourced bathymetry were included.

The data from each bathymetry source were gridded individually at 100-meter resolution and then merged. After merging, the output was reclassed as follows. “Minimally mapped” (pink) is any cell with at least one sounding. A grid cell supported by three or more soundings is referred to as “better mapped” (purple). This map was compiled in January 2022. The analysis will be repeated biannually.



	1 Atlantic & Gulf of Mexico	2 Great Lakes	3 Caribbean	4 Alaska	5 Pacific (CA, OR, WA)	6 Pac. Remote Isl. & Hawaii	Total Across Regions
Total Area (sq nm)	472,200	45,100	61,600	1,080,200	239,700	1,691,700	3,590,500
Area Mapped in Jan 2022 (sq nm)	282,900	3,200	35,900	335,900	192,700	878,400	1,729,000
% Mapped	60%	7%	58%	31%	80%	52%	48%

Figure 13. U.S. bathymetric coverage and gap analysis as of January 2022. Areas shown in purple are supported by three or more soundings per 100 sq. mi. Areas in pink are supported by at least one sounding per 100 sq. mi. Image source: NOAA

3.5.3. IWG-OCM 2021 Prioritization Surveys

The IWG-OCM conducted multiple Spatial Priorities Studies, which comprehensively gathered the priorities of ocean and coastal mapping partners and those that rely on coastal and ocean mapping data. This study asked IWG-OCM partners to define areas where they need mapping data in our oceans, coasts and Great Lakes, and say briefly why and what they want to do with it. This work was done in support of the NOMEC Strategy.

These studies will allow IWG-OCM partners to see where there are overlaps in requirements so that resources can be allocated efficiently. Other study goals include enabling participants to better coordinate and leverage resources where there is a shared mapping need.

So far, four prioritization studies have been completed:

- NOAA Spatial Priorities Study (nationwide, NOAA offices only);
- Great Lakes Spatial Priorities Study (Great Lakes region only, government and non-government participants);
- IWG-OCM Spatial Priorities Study (nationwide, federal agencies only); and

- Alaska Spatial Priorities Study (Alaska region only, government and non-government participants).

A fifth Spatial Priorities Study is in progress for the Mid-Atlantic (encompassing the states of Virginia, Delaware, Maryland, New Jersey, and New York). This study will survey regional stakeholders, including state governments, local governments, tribal governments and corporations, fisheries organizations, academia, and other interest groups on their mapping needs and priorities.

The studies are expected to help support NOMEC Strategy goals by making it easier for mapping organizations to identify shared areas of interest.

3.6. USGS 3D National Topography Model Call for Action: 3D Hydrography Program

Topography is defined by terrain and water, each influencing and shaping the other. The 3D National Topography Model (3DNTM) is a USGS initiative that updates and integrates USGS elevation and hydrography data, and encodes these co-dependent topographic relationships into a single, 3D model. It enables analysis and visualization for the broad range of the Nation's environmental, climate, and infrastructure applications.

The vision for a 3DNTM is an outgrowth of the NEEA and the Hydrography Requirements and Benefits Study (HRBS) both of which call for a more integrated approach for managing data and provisioning information. This approach became apparent when the NEEA and HRBS revealed common requirements for high-quality elevation and hydrography data across multiple disciplines.

The 3DNTM ensures that the core data meet the most demanding scientific requirements and that data-driven decisions are enabled across user communities. There is a clear set of core requirements that can be most cost-effectively met with high-quality nationwide integrated elevation and hydrography data. While specialized products will support each of the user communities, sound decisions are best supported by hydrography and elevation data of common lineage.

The vision of the 3DNTM is to integrate USGS elevation and hydrography datasets to model the Nation's topography in 3D to support day-to-day water management needs and inform emerging U.S. climate and water policies. The new initiative consists of four development tracks:

- Complete nationwide elevation and hydrography baseline datasets;
- Conduct pilot studies to test new approaches for integrating hydrography and elevation data;
- Design and implement the next generation of integrated hydrography and elevation data; and

- Research and develop a 3D data model to meet the Nation's most urgent needs; the data, products and services will be managed under the umbrella of the 3DNTM initiative.

Development of the 3D Hydrography Program (3DHP) Call for Action is Part 1 of a larger USGS strategic plan for the 3DNTM. Part 2 will include the Call for Action for the next generation of the 3DEP based on the 3D Nation Elevation Requirements and Benefits Study results.

3.7. 3D Nation Concept

The 3DNTM, the NCMS 1.0, and the NOMEC Strategy and Implementation Plan recognize the importance of 3D elevation data and coordination of mapping efforts on the land and in the seas.

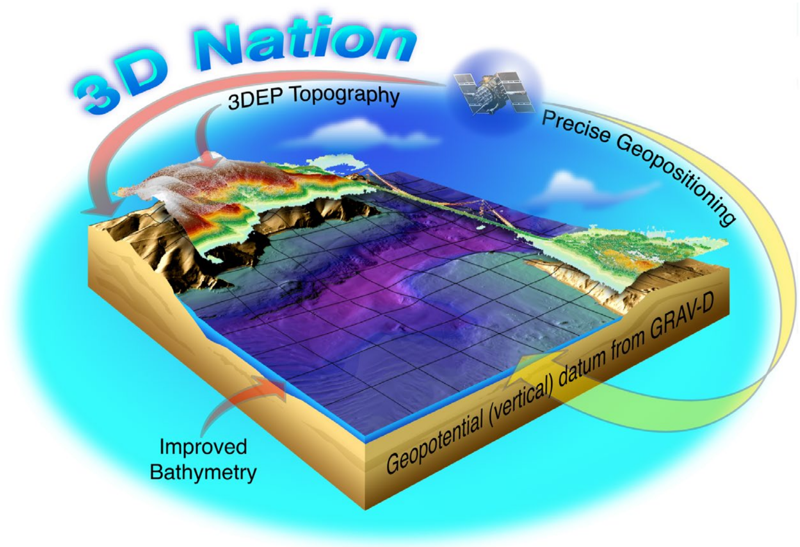


Figure 14. 3D Nation concept

The vision of a 3D Nation is to make communities more resilient and the U.S. economy more competitive by building a modern, accurate elevation foundation from our highest mountains to our deepest oceans. 3D Nation unites terrestrial and ocean/coastal mapping agencies in the common purpose to achieve an authoritative national geospatial foundation in support of national mapping needs.

3D Nation serves as a unifying structure for all national elevation efforts and provides a consistent set of standards and objectives to ensure public access to an accurate, authoritative national elevation dataset.

3.8. 3D Nation Study Context

As depicted in Figure 15, the U.S. coastal zone represents the interface between the areas mapped by the IWG-OCM and 3DEP. The IWG-OCM represents the bathymetric mapping community that maps bathymetric surfaces to include offshore and nearshore areas, the intertidal zone, beaches, and submerged objects that pose a threat to marine navigation. 3DEP represents the topographic mapping community that maps the tops of structures/vegetation and the bare earth terrain to include the beach and intertidal zone. Thus, both mapping communities share interest in mapping the intertidal zone and beach areas shown. USGS, USACE, and Federal Emergency Management Agency (FEMA) are among the stakeholders interested in mapping inland bathymetry (rivers and lakes).

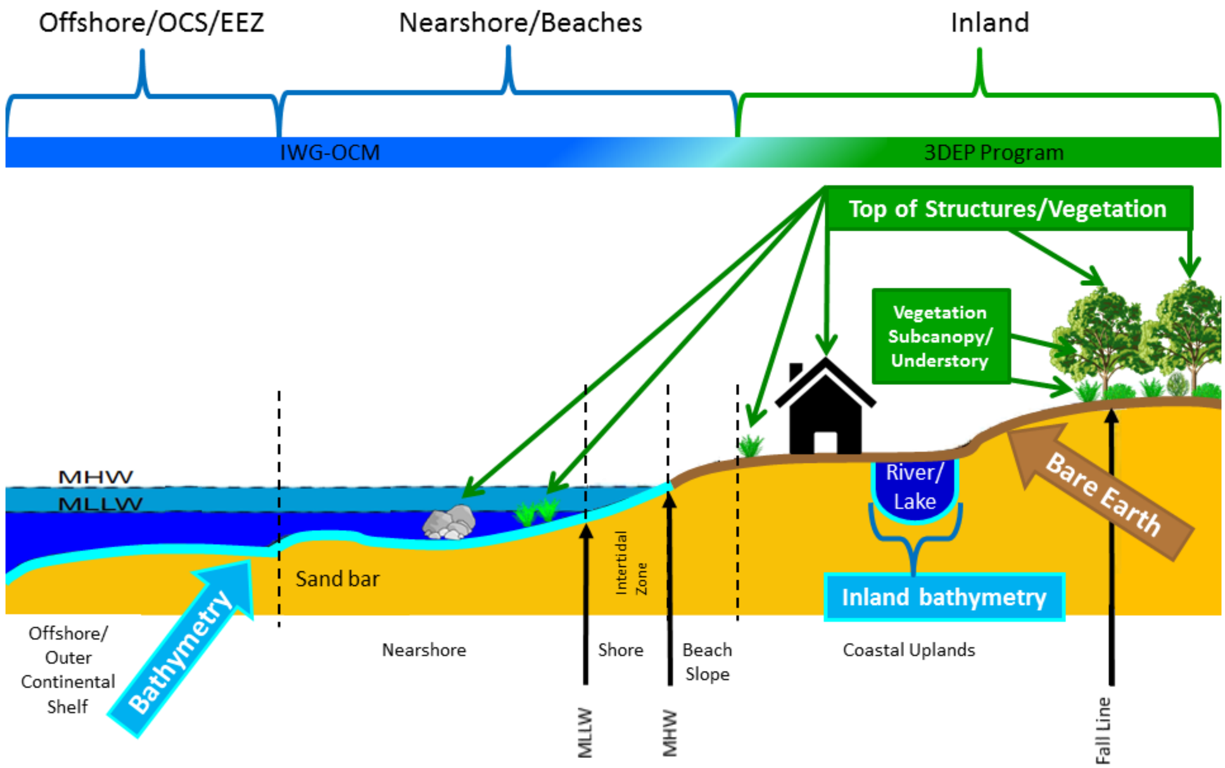


Figure 15. The U.S. coastal zone representing the interface between topography and bathymetry.

Within the context of the 3D Nation Elevation Requirements and Benefits Study, four areas of interest were defined and used to organize and map the areas of interest of the study participants. The four areas are as follows.

Inland Topography - In Figure 15, "Inland topography" does not end at the top of the beach slope but typically includes the beach area, sometimes as far out as the MLLW line, if tidal conditions permit, to map all land areas that are not submerged. Inland topography refers to data collected on land, and may include the land surface, features and objects on land such as building structures and vegetation, as well as bare earth topography under vegetation.

Inland Bathymetry - Inland bathymetry refers to data collected on the bottoms of lakes, reservoirs, and rivers and may include submerged features such as structures, objects, or vegetation.

Nearshore Bathymetry - The nearshore includes coastal waters seaward from the MLLW line well beyond the surf zone and includes the area influenced by coastal currents. It also includes the coastal waters along the Great Lakes. But there is no clear boundary between nearshore and offshore. For the purpose of this study, nearshore bathymetry pertains to coastal areas to a depth of about 10 meters (20 meters in the Florida Keys and elsewhere where waters are exceptionally clear).

Offshore Bathymetry - For the purpose of this study, offshore bathymetry pertains to areas deeper than 10 meters including the Great Lakes.

3.9. 3D Nation Study Definitions

The following terms are used throughout this report and are defined as follows.

Mission Critical Activity – Mission Critical is defined herein as "indispensable for mission accomplishment and/or essential for effective/efficient operations in accomplishing the core mission of the organization." Examples might include such activities as oil and gas exploration, dam break modeling and coastal inundation mapping, commercial shipping, or farm pond design and agricultural optimization.

Business Use – The ultimate use of services or products from MCAs to accomplish an organized mission. The 30 Business Uses are listed in Table 13 and are further defined in Appendix E.

Geography Type – In the context of this study, the term Geography Type is used as a category that encompasses the types of elevation data needed for the geographic area(s) of interest as expressed by the study respondents. This includes inland land areas (i.e., Inland Topography), inland waters (i.e., Inland Bathymetry), nearshore and beach areas including the Great Lakes (i.e., Nearshore Bathymetry), and offshore areas including the Outer Continental Shelf, the EEZ, and the Great Lakes (i.e., Offshore Bathymetry).

4. Study Process

This section provides a summary of the 3D Nation Elevation Requirements and Benefits Study process, to include (1) developing the study questionnaire; (2) outreach and training activities related to the questionnaire; (3) administering the online questionnaire; (4) developing a GDB to store the study data; (5) conducting validation meetings with each state, federal agency, and non-governmental entity that responded to the questionnaire; (6) collecting cost information and selecting program implementation scenarios; (7) developing tools that were used to analyze study results and evaluate program implementation scenarios using B/C and ROI Analyses; and (8) documentation of the study results in this final report.

Figure 16 provides a flow chart illustrating this process.

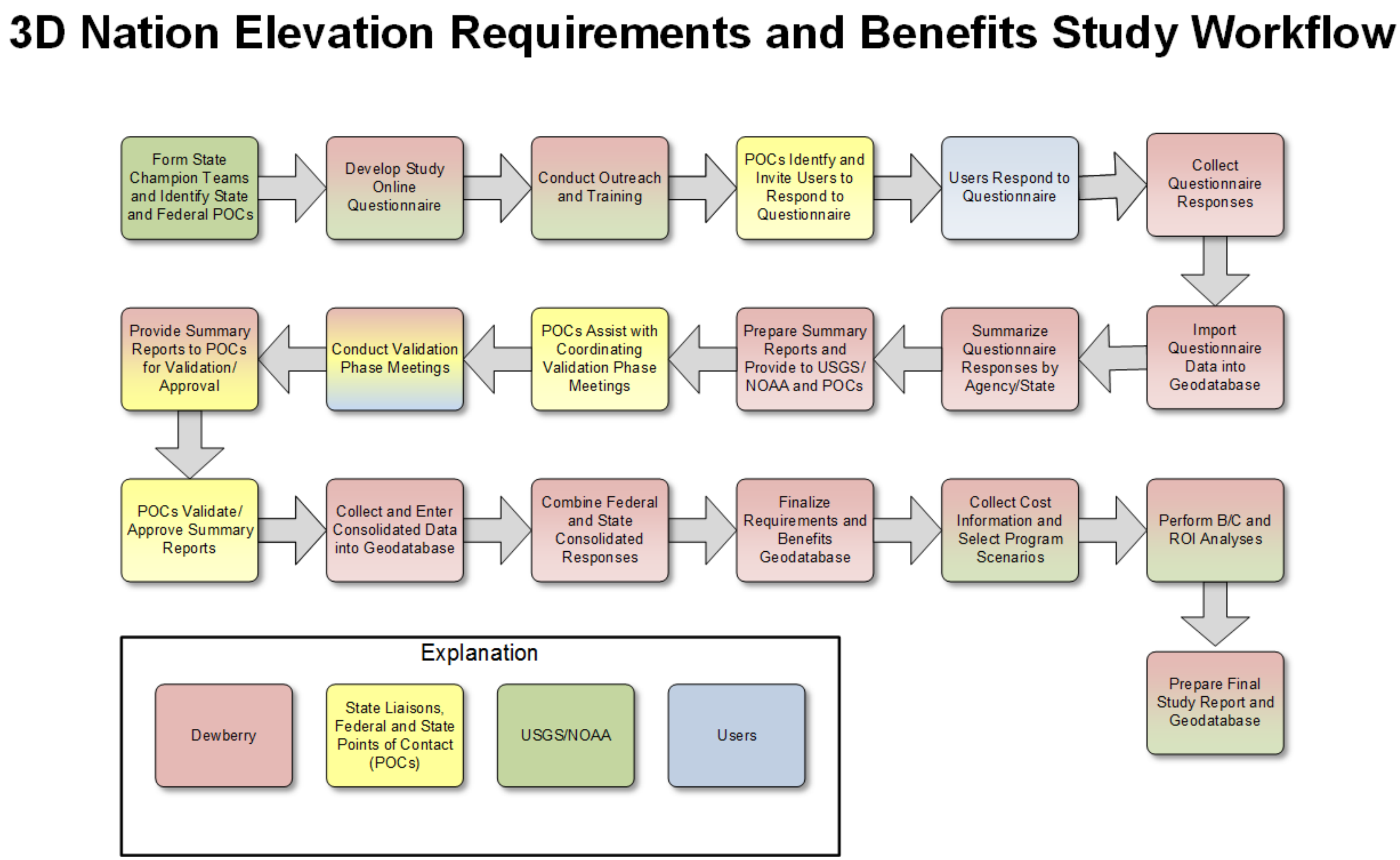


Figure 16. 3D Nation Elevation Requirements and Benefits Study workflow

4.1. Project Management Plan

Dewberry developed a detailed project management plan for the study that outlined procedures to be followed in developing the MCA collection methodology; designing the project GDBs; designing the online questionnaire; developing training workshops; gaining responses to the online questionnaire and managing those responses; populating the GDB with the questionnaire responses; preparing for and conducting follow-on validation phase meetings; populating the GDB with the validation phase meeting results from federal, state, and other non-governmental respondents; and other information needed to execute the full Scope of Work for this task order. This plan provided Dewberry's strategy to design the collection efforts with the end uses of the information in mind.

4.2. Questionnaire Development

The initial study questions were developed and subsequently refined in response to review comments provided by USGS and NOAA study partners, beta testers, OMB, and as the online questionnaire was programmed. The complete online questionnaire is provided in Appendix A.

Because the online questionnaire was administered to state representatives and other respondents, OMB approval was required. A Federal Register Notice was published on February 24, 2017 (82 FR 11558), soliciting public comments on the study. The questionnaire and associated paperwork were submitted to OMB for review and approval on December 20, 2017. The questionnaire was modified several times in response to numerous OMB comments. Final OMB approval (OMB Control Number 0648-0762) for the questionnaire was received on May 21, 2018. The online questionnaire was opened to study participants on June 21, 2018. An extension of the information collection was requested from OMB on April 16, 2021 and granted on August 2, 2021, extending the expiration date to August 31, 2024.

4.3. FAQs and Benefits Examples

The questionnaire was accompanied by a list of Frequently Asked Questions (FAQ) pertaining to the major elevation data terms used throughout the questionnaire. Hyperlinks were also provided within the questionnaire to the relevant FAQs as the terms were used. The FAQs are provided in Appendix B. A second tutorial also accompanied the questionnaire with examples of some of the types of benefits respondents might receive from improved elevation information. It included methods for estimating financial benefits, which respondents were asked to estimate for each MCA. The benefits examples were also hyperlinked within the questionnaire to the relevant questions about benefits. The benefits examples tutorial is provided in Appendix C.

4.4. Outreach and Training

Points of Contact at federal agencies and state champions for each state were identified prior to launching the online questionnaire. Federal agency POCs were selected by the participating agencies. For each state, one or more leaders in the elevation community were identified as state champions by USGS National Map Liaisons and NOAA liaisons working with their local and state Geographic Information Systems (GIS) coordination contacts. These state leaders were primarily GIS managers, leaders, and coordinators within state government. Letters of invitation were sent by USGS and NOAA. Each letter briefly outlined the purpose of the study, expected roles for the POCs and champions, and invited them to outreach training workshops. The training workshops served to inform the attendees of the goals of the study, the process for collecting data from respondents, and expectations of the roles the study participants would play.

Following the training workshops, the federal agency POCs and state champions were asked to identify study participants from their respective agency and state. Once the lists of study participants had been collected, outreach and training were also conducted for study participants.

A separate process to identify non-governmental study participants with elevation data needs was used. A list of professional organizations, trade associations, not-for-profits, private entities, academic programs, councils, and other stakeholder organizations with POCs was developed. These identified POCs received a letter from USGS and NOAA which briefly outlined the purpose of the study and encouraged them to invite their members to attend one of the online training workshops and participate in the study.

4.5. Questionnaire Administration

Dewberry administered the online questionnaire for the designated federal, state, and other non-governmental agencies using CheckBox survey software. The survey was hosted on premises on a NOAA server. The survey was opened for respondents on June 21, 2018 and remained open for additional responses throughout the validation phase.

An email list of study participants with elevation data experience and needs was obtained from the federal POCs and the state champions. Invitations with user-specific links to the questionnaire were originally sent to 799 state participants and 658 federal participants. An open link to the questionnaire was sent to 185 non-governmental POCs with an invitation to forward the link to interested member participants. Additional participation was solicited throughout the validation phase.

4.6. Study Geodatabase

Dewberry designed and developed a schema for a file GDB to store the questionnaire responses. The GDB schema was designed in conjunction with the questionnaire and keeping in mind the need to support aggregation of responses in multiple ways (e.g., by geography, agency, requirements, Business Use, etc.). It was also designed to support analysis of the most significant requirements, production of summary reports, and development of future analysis tools.

All questionnaire responses are included in the study GDB. Each response is linked to its spatial footprint(s) and separate spatial footprints are included for the Inland Topography, Inland Bathymetry, Nearshore Bathymetry, and Offshore Bathymetry portions of each MCA as applicable.

- Standard polygons for spatial features such as states, counties, and select federal lands were derived from USGS small scale datasets.
- Standard polygons for Hydrologic Unit Codes (HUC) were derived from the Water Boundary Dataset.
- Standard polygons for national marine sanctuaries and marine national monuments were derived from NOAA Office of National Marine Sanctuaries datasets.
- Standard polygons for maritime boundaries were derived from NOAA National Ocean Service, OCS datasets. Navigationally significant areas were derived from Bureau of Ocean Energy Management (BOEM) depth contours and the descriptions of the navigationally significant areas.
- Standard polygons for nearshore areas were generated from a 10-meter depth contour.
- Non-standard user-defined polygons are also supported.

The study GDB is accompanied by metadata and documentation on the database structure and its use. A data dictionary and Entity Relationship diagram for the consolidated study GDB are provided in Appendix D.

4.7. Draft Summary Reports

Using the study GDB, Dewberry prepared draft summary reports of the online questionnaire results for each of the participating federal agencies, states, and territories. These summary reports were provided to the federal agency POCs and the state champions in preparation for conducting the validation phase meetings. Clean summary reports that reflect all changes made during the validation process are included as appendixes to this report.

4.8. Validation Meetings

As part of the validation process, Dewberry conducted interviews/workshops with key managers and 3D elevation data users from the state, regional, county, local, and Tribal government entities as well as the federal agencies and the not-for-profit and private organizations that responded to the online questionnaire. These were primarily virtual sessions (webinar and conference call) conducted as group sessions for a given state, agency, or organization. A few were conducted in person. After ascertaining that it was agreeable to the attendees, the interviews were recorded. The validation meetings were attended by the federal POCs or state champions, USGS and/or NOAA representatives, and individual questionnaire respondents who were able to attend.

Dewberry hosted and documented each validation meeting. During the federal government shutdown from December 2018 to January 2019, Dewberry was given permission to continue conducting meetings with available states, agencies, and organizations without USGS and NOAA representatives present.

During the validation meetings, a draft summary report of the information submitted in the questionnaire for the state, agency, or organization was reviewed in detail. Each questionnaire respondent in attendance was asked to provide a brief overview of his or her use of elevation data and to respond to individual questions regarding any gaps in information or potential discrepancies in questionnaire responses. Changes or additions to the draft summary report were documented during the meetings. In many cases, follow up meetings were scheduled to gather additional information from questionnaire respondents who were unable to attend the initial validation meeting. In some case, the follow ups were done via email exchange.

The validation meetings served to do the following:

- Document activities associated with the MCAs;
- Consolidate duplicate or similar MCAs within the agency or organization;
- Summarize and validate 3D elevation data requirements;
- Fill any questionnaire gaps; and
- Validate tangible and intangible benefits associated with the MCAs.

During the validation meetings states, agencies, and organizations were also asked to provide a narrative for inclusion in the final summary report.

After the validation meetings were completed, summary statistics of the validated responses were generated from the study GDB and reviewed. It was noted that MCAs were missing for Business Uses where they would be expected to be important. For instance, a state with a long coastline but no MCA for coastal zone management or a federal agency with a mission of public land management but no MCA for wildfire management or recreation would be noted. Each state and agency was presented with information regarding potentially missing Business Uses and provided an opportunity to expand their requirements and benefits. Select Business Uses were highlighted in a table at the beginning of a report for particular attention by the state or agency.

4.9. Final Summary Reports

Each state, agency, or organization was given a clean summary of their consolidated responses and asked to sign off that the summary accurately represents their requirements and benefits for 3D elevation data. The approved summary reports are included as appendixes to this report.

4.10. Study Results Analysis

A GIS-based analysis tool, named herein the 3D Nation Analysis Tool, was developed to analyze the study results and evaluate program implementation scenarios. The 3D Nation Analysis Tool allows a user to specify variables such as the cost of data acquisition and program implementation options (e.g., geography covered, update frequency, Quality Level delivered, other requirements met). Furthermore, the 3D Nation Analysis Tool is designed to accommodate program implementation scenarios with cost analyses that vary by technology and geography. As an example, the cost for topographic lidar is different than that for bathymetric lidar, and these costs may change over time, and each of these technologies is applicable to a different geographic area. The 3D Nation Analysis Tool is flexible enough to accommodate these and other future scenarios.

All geospatial analyses performed within the 3D Nation Analysis Tool are performed within a 1km grid that is overlaid on the study GDB polygons. The 3D Nation Analysis Tool performs geospatial calculations of the cost for data acquisition per grid cell. Benefits are calculated by summing all of the dollar benefits from the intersecting MCA areas of interest per grid cell.

In addition to performing program implementation analyses, the 3D Nation Analysis Tool provides the option to generate maps. The 3D Nation Analysis Tool supports the generation of reports that summarize benefits by multiple user-determined variables. Additionally, the 3D Nation Analysis Tool supports the ability to map requirements or benefits by pre-determined geographies (e.g., states or HUCs) selected by the user. The 3D Nation Analysis Tool also supports comparison of the costs and benefits of implementing different programs that satisfy different requirements and supports comparison to other cost models.

The 3D Nation Analysis Tool is accompanied by user documentation that includes system requirements, installation procedures, step-by-step procedures for using the 3D Nation Analysis Tool with screen shots, and sample output (e.g., reports, charts, maps).

The Government provided cost information for input into the BCA and ROI analyses. USGS provided average costs for acquisition of topographic lidar at a range of Quality Levels and also provided cost range estimates for QL0B and QL2B topobathymetric lidar for Inland Bathymetry. NOAA and USACE provided average cost ranges for topobathymetric lidar for Nearshore Bathymetry, and NOAA provided information on historic costs for hydrographic surveys in different areas for Offshore Bathymetry.

Based on the study results and the interests of USGS and NOAA, several program implementation scenarios that address user requirements, refresh cycles, technical considerations, feasibility, and benefit-cost considerations were developed. These program implementation scenarios were analyzed using the 3D Nation Analysis Tool and BCA and ROI Analyses were performed and reviewed.

Finally, the study results are documented in this report which summarizes the entire study, including the methodology, the gathered requirements and benefits information, the analyses performed, and the results of those analyses along with some final observations and conclusions.

5. Study Results

This section provides a brief summary of the 3D Nation Elevation Requirements and Benefits Study responses. The study results are summarized by the number of MCAs by organization type, geography type (Inland Topography, Inland Bathymetry, Nearshore Bathymetry, and Offshore Bathymetry); user requirements for 3D elevation data including Quality Level and update frequency reported as number of MCAs and broken out by geography type; and number of MCAs by Business Use. Additionally, quantified future annual benefits are summarized by organization type, geography type, and Business Use.

Note that the details of the Business Uses are provided in Appendix E. Details of the MCAs are provided in Appendix F (federal agencies), Appendix G (state, regional, county, city or other local governments and territories), Appendix H (private entities), and Appendix I (not-for-profit entities and associations).

Note that the information presented herein reflects the data provided by study respondents at the time of query, which may range from 2018 to 2021. Geospatial areas of interest boundaries as well as future annual benefits estimates may have changed since the time the information was originally provided.

5.1. Study Participation

Study participants were selected by the federal POCs, state champions, and USGS and NOAA liaisons. The federal POCs and state champions were asked to select individuals who use elevation data to address their business needs.

Study respondents reported a total of 1,352 MCAs. The responses are broken down by organization type and geography type, as shown in Table 13.

Note that there is some overlap in how organizations were categorized. A total of 36 academic institutions with 56 MCAs are grouped with state responses because they were identified by the state champion and appear to perform functions that are mainly within the state, including some that house the state geological survey and some that house the state's geospatial clearinghouse. The 14 academic institutions that are reported separately are those that expressed a need for nationwide data. Similarly, 14 private entities with 14 MCAs are grouped with state responses because they were identified by the state champion and appear to perform functions that are mainly within the state, including several private utility corporations as well as several engineering firms that do a large amount of work for the state. Three additional not-for-profit entities with eight MCAs are also grouped with the state responses. These include several state offices of The Nature Conservancy that perform conservation activities within individual states.

Table 8. Summary of organizational types

Organization Type	Number of Agencies/ Entities	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Percent of MCAs
Federal Agencies and Commissions	45	198	16%	144	17%	129	19%	89	24%	209	15%
Academia	14	14	1%	11	1%	11	2%	6	2%	14	1%
Not-for-profit	10	7	1%	4	0%	6	1%	5	1%	11	1%
Private or Commercial	34	33	3%	21	3%	24	4%	14	4%	44	3%
States including State, Regional, County, Local, or Territory Government	56	1,011	79%	644	77%	489	74%	254	69%	1,074	79%
Tribal Government*	8	9	1%	7	1%	3	0%	2	1%	10	1%
Total		1,272	100%	831	100%	662	100%	370	100%	1,352	100%

* Tribal government numbers are also included in the state totals

5.2. Mission Critical Activities

Study participants were asked to describe in their own words their MCAs. Because the MCAs were self-described and titled, there was a wide variety among the MCAs. Some MCAs were described in terms of the respondent's agency's organization, some in terms of their daily activities. Some MCAs were very broad and encompassed multiple Business Uses and some were quite narrowly defined.

As noted above, after consolidation of the data during the follow-on interviews/workshops and validation processes, 1,352 MCAs were described. In general, the federal agencies were found to have had multiple questionnaire respondents who described the same or very similar MCAs, in many cases coming from varying regional perspectives. During the consolidation process, these MCAs were combined such that the MCAs for each agency were unique. On the other hand, during the state interview/workshop process, 672 new MCAs were identified that had not been originally captured by the respondents to the questionnaire. These new MCAs were added to fill gaps in information provided by the states.

As noted previously, study respondents were asked to identify the geographic area requirements for each MCA. Maps depicting the area of interest for each MCA are included in Appendices F, G, and H. Figure 17 shows the distribution of the number of MCAs by state. Figure 17 shows the spatial extents of the MCAs. Areas with darker colors have greater numbers of areas of interest.

Tables 9 – 11 list the details of the number of MCAs by the participating federal agencies; state, regional, county, city or other local governments and territories; and tribal governments.

5.2.1. Number of MCAs by Federal Agency

Table 9 shows the breakdown of the MCAs submitted by the participating federal agencies.

Table 9. Summary of the MCAs submitted by federal agencies

Agency Name	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of Federal MCAs
U.S. Air Force (USAF)	15	8%	0	0%	1	1%	0	0%	15	7%
Animal and Plant Health Inspection Service (APHIS)	1	1%	0	0%	0	0%	0	0%	1	0%
Agricultural Research Service (ARS)	1	1%	1	1%	1	1%	0	0%	1	0%
Bureau of Indian Affairs (BIA)	1	1%	1	1%	1	1%	0	0%	1	0%
Bureau of Land Management (BLM)	9	5%	4	3%	0	0%	0	0%	9	4%
Bureau of Ocean Energy Management (BOEM)	0	0%	0	0%	3	2%	3	3%	3	1%
Centers for Disease Control and Prevention (CDC)	8	4%	8	6%	8	6%	8	9%	8	4%
U.S Census Bureau	2	1%	0	0%	0	0%	0	0%	2	1%
U.S. Committee on the Marine Transportation Systems (CMTS)	9	5%	10	7%	10	8%	10	11%	10	5%
Department of Homeland Security (DHS)	4	2%	2	1%	1	1%	1	1%	4	2%
Defense Installations Spatial Data Infrastructure (DISDI)	4	2%	2	1%	1	1%	0	0%	4	2%
National Renewable Energy Laboratory (NREL)	1	1%	0	0%	1	1%	1	1%	1	0%
Department of Labor Bureau of Labor Statistics (DOL BLS)	0	0%	0	0%	0	0%	0	0%	0	0%
Defense Threat Reduction Agency (DTRA)	2	1%	2	1%	1	1%	1	1%	2	1%
Environmental Protection Agency (EPA)	5	3%	4	3%	4	3%	3	3%	5	2%
Federal Aviation Administration (FAA)	4	2%	0	0%	4	3%	4	4%	4	2%
Federal Bureau of Investigation (FBI)	13	7%	13	9%	13	10%	12	13%	13	6%
Federal Communications Commission (FCC)	1	1%	1	1%	1	1%	1	1%	1	0%

Agency Name	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of Federal MCAs
Federal Emergency Management Agency (FEMA)	2	1%	2	1%	2	2%	1	1%	2	1%
Federal Energy Regulatory Commission (FERC)	6	3%	6	4%	1	1%	1	1%	6	3%
Federal Highway Administration (FHWA)	1	1%	1	1%	0	0%	0	0%	1	0%
Federal Motor Carrier Safety Administration (FMCSA)*	0	0%	0	0%	0	0%	0	0%	0	0%
Federal Railway Administration (FRA)	1	1%	0	0%	0	0%	0	0%	1	0%
Farm Service Agency (FSA)	3	2%	0	0%	0	0%	0	0%	3	1%
Fish and Wildlife Service (FWS)	2	1%	2	1%	2	2%	1	1%	2	1%
Great Lakes Commission (GLC)*	0	0%	0	0%	0	0%	0	0%	0	0%
International Boundary and Water Commission (IBWC)	4	2%	4	3%	3	2%	0	0%	4	2%
International Joint Commission (IJC)	1	1%	1	1%	0	0%	0	0%	1	0%
Maritime Administration (MARAD)	2	1%	2	1%	3	2%	3	3%	3	1%
National Aeronautics and Space Administration (NASA)	4	2%	2	1%	2	2%	0	0%	4	2%
U.S. Navy (USN)	2	1%	2	1%	2	2%	2	2%	2	1%
National Geospatial-Intelligence Agency (NGA)	1	1%	0	0%	1	1%	1	1%	2	1%
National Oceanic and Atmospheric Administration (NOAA)	15	8%	11	8%	15	12%	10	11%	18	9%
National Park Service (NPS)	14	7%	12	8%	10	8%	1	1%	14	7%
Nuclear Regulatory Commission (NRC)	5	3%	4	3%	4	3%	3	3%	5	2%
Natural Resources Conservation Service (NRCS)	2	1%	2	1%	1	1%	0	0%	2	1%
Oak Ridge National Laboratory (ORNL)	1	1%	1	1%	1	1%	0	0%	1	0%
Office of Surface Mining Reclamation and Enforcement (OSMRE)	1	1%	1	1%	0	0%	0	0%	1	0%
Pipeline and Hazardous Materials Safety Administration (PHMSA)	1	1%	1	1%	0	0%	0	0%	1	0%
Smithsonian Institution (SI)	10	5%	9	6%	9	7%	8	9%	10	5%
Tennessee Valley Authority (TVA)	3	2%	3	2%	0	0%	0	0%	3	1%
U.S. Army Corps of Engineers (USACE)	7	4%	7	5%	6	5%	3	3%	8	4%

Agency Name	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of Federal MCAs
U.S. Arctic Research Commission (USARC)	1	1%	1	1%	1	1%	1	1%	1	0%
U.S. Bureau of Reclamation (USBR)	3	2%	3	2%	0	0%	0	0%	3	1%
U.S. Coast Guard (USCG)	1	1%	1	1%	1	1%	1	1%	1	0%
U.S. Forest Service (USFS)	5	3%	3	2%	1	1%	0	0%	5	2%
U.S. Geological Survey (USGS)	18	9%	13	9%	12	9%	8	9%	19	9%
U.S. Marine Corps (USMC)	2	1%	2	1%	2	2%	1	1%	2	1%
Total	198	100%	144	100%	129	100%	89	100%	209	100%

* Dropped out of study

5.2.2. Number of MCAs by State

Table 10 shows a summary of the MCAs submitted by state, regional, county, city, or other local government entities by state. Note that the eight Tribal governments are included in the counts for the states but also listed separately in Table 11.

Table 10. Summary of the MCAs submitted by state (including tribal governments)

State Name	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of State MCAs
Alabama (AL)	12	1%	8	1%	8	2%	5	2%	12	1%
Alaska (AK)	33	3%	27	4%	27	5%	13	5%	33	3%
American Samoa (AS)	15	1%	12	2%	12	2%	3	1%	15	1%
Arizona (AZ)	14	1%	7	1%	0	0%	0	0%	14	1%
Arkansas (AR)	9	1%	4	1%	0	0%	0	0%	9	1%
California (CA)	35	3%	21	3%	19	4%	10	4%	35	3%
Colorado (CO)	8	1%	4	1%	0	0%	0	0%	8	1%
Connecticut (CT)	23	2%	18	3%	17	3%	8	3%	24	2%
Delaware (DE)	17	2%	14	2%	15	3%	6	2%	17	2%
District of Columbia (DC)	6	1%	3	0%	3	1%	0	0%	6	1%

State Name	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of State MCAs
Florida (FL)	24	2%	20	3%	23	5%	10	4%	30	3%
Georgia (GA)	8	1%	2	0%	3	1%	1	0%	8	1%
Guam (GU)	27	3%	8	1%	18	4%	9	4%	28	3%
Hawai'i (HI)	27	3%	15	2%	16	3%	8	3%	29	3%
Idaho (ID)	14	1%	8	1%	0	0%	0	0%	15	1%
Illinois (IL)	24	2%	17	3%	8	2%	7	3%	27	3%
Indiana (IN)	27	3%	9	1%	9	2%	0	0%	27	3%
Iowa (IA)	19	2%	13	2%	0	0%	0	0%	20	2%
Kansas (KS)	12	1%	3	0%	0	0%	0	0%	12	1%
Kentucky (KY)	13	1%	4	1%	0	0%	0	0%	13	1%
Louisiana (LA)	16	2%	15	2%	15	3%	11	4%	18	2%
Maine (ME)	17	2%	12	2%	14	3%	11	4%	18	2%
Maryland (MD)	22	2%	14	2%	15	3%	6	2%	24	2%
Massachusetts (MA)	16	2%	9	1%	15	3%	6	2%	19	2%
Michigan (MI)	17	2%	12	2%	14	3%	10	4%	18	2%
Minnesota (MN)	37	4%	33	5%	30	6%	14	5%	37	3%
Mississippi (MS)	16	2%	11	2%	6	1%	2	1%	19	2%
Missouri (MO)	7	1%	6	1%	0	0%	0	0%	7	1%
Montana (MT)	27	3%	12	2%	0	0%	0	0%	28	3%
Nebraska (NE)	18	2%	6	1%	0	0%	0	0%	18	2%
Nevada (NV)	22	2%	8	1%	0	0%	0	0%	22	2%
New Hampshire (NH)	7	1%	5	1%	6	1%	0	0%	7	1%
New Jersey (NJ)	22	2%	14	2%	16	3%	8	3%	25	2%
New Mexico (NM)	23	2%	6	1%	0	0%	0	0%	23	2%
New York (NY)	10	1%	6	1%	5	1%	1	0%	10	1%
North Carolina (NC)	29	3%	23	4%	21	4%	17	7%	29	3%
North Dakota (ND)	4	0%	3	0%	0	0%	0	0%	4	0%
Northern Mariana Islands (CNMI)	8	1%	3	0%	9	2%	6	2%	10	1%
Ohio (OH)	16	2%	10	2%	13	3%	10	4%	19	2%
Oklahoma (OK)	11	1%	10	2%	0	0%	0	0%	11	1%
Oregon (OR)	19	2%	15	2%	14	3%	4	2%	22	2%
Pennsylvania (PA)	19	2%	14	2%	10	2%	3	1%	19	2%
Puerto Rico (PR)	1	0%	1	0%	1	0%	1	0%	1	0%

State Name	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of State MCAs
Rhode Island (RI)	32	3%	27	4%	24	5%	16	6%	32	3%
South Carolina (SC)	17	2%	17	3%	17	3%	13	5%	17	2%
South Dakota (SD)	19	2%	7	1%	0	0%	0	0%	19	2%
Tennessee (TN)	14	1%	8	1%	0	0%	0	0%	17	2%
Texas (TX)	25	2%	18	3%	13	3%	5	2%	25	2%
U.S. Virgin Islands (USVI)	11	1%	4	1%	11	2%	4	2%	15	1%
Utah (UT)	27	3%	6	1%	0	0%	0	0%	27	3%
Vermont (VT)	16	2%	16	2%	0	0%	0	0%	18	2%
Virginia (VA)	26	3%	19	3%	19	4%	9	4%	29	3%
Washington (WA)	27	3%	27	4%	21	4%	16	6%	29	3%
West Virginia (WV)	10	1%	5	1%	0	0%	0	0%	10	1%
Wisconsin (WI)	19	2%	9	1%	5	1%	3	1%	20	2%
Wyoming (WY)	26	3%	23	4%	0	0%	0	0%	26	2%
Total	1,020	100%	651	100%	492	100%	256	100%	1,074	100%

Figure 17 shows the spatial distribution of the total number of MCAs per state.

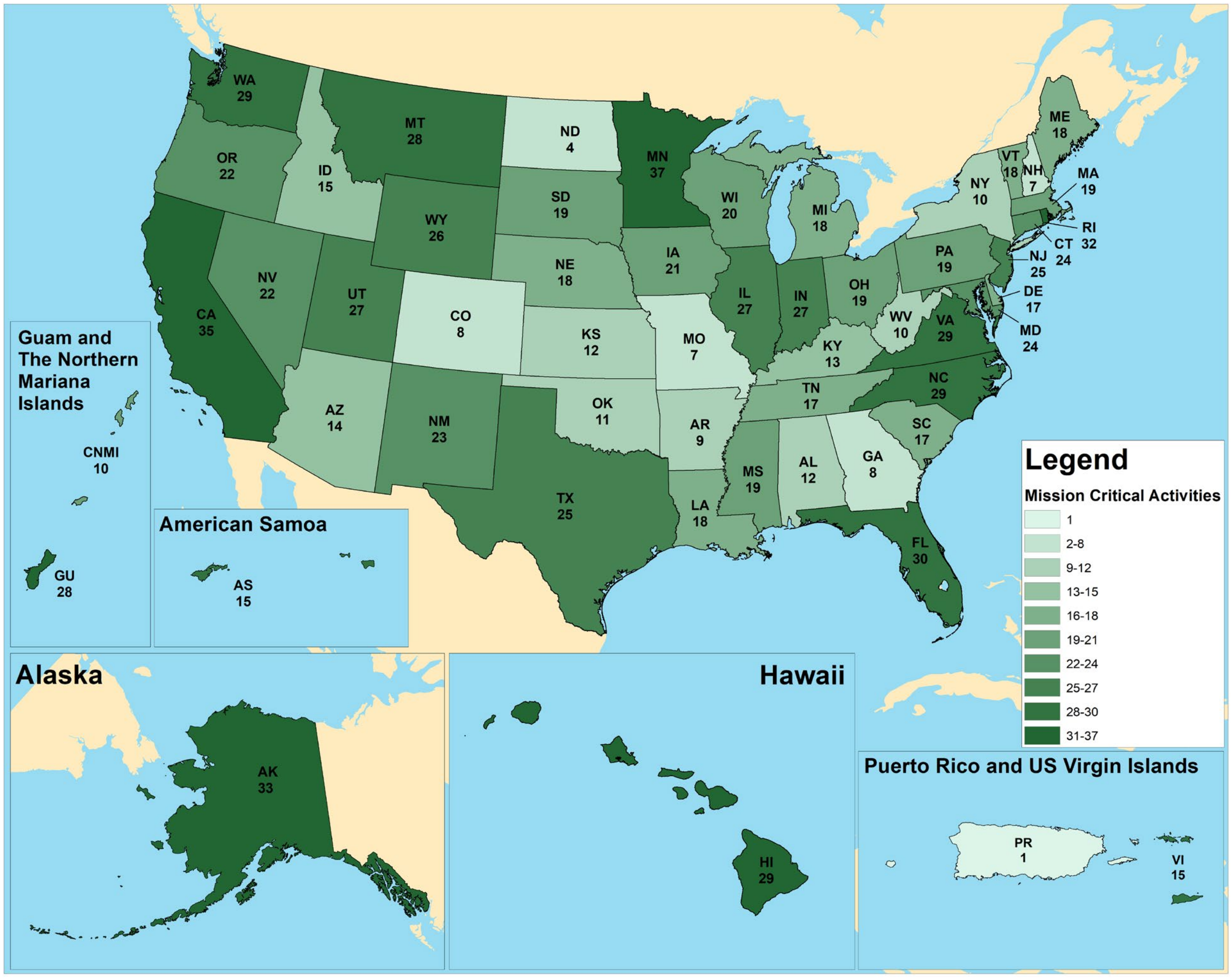


Figure 17. Map showing total number of MCAs per state

5.2.4. Number of MCAs by Tribal Government

Table 11 shows the eight tribal governments that submitted MCAs.

Table 11. Summary of the eight tribal governments that submitted MCAs

Tribal Government Name	State	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Number of MCAs	Pct. of Tribal MCAs
Bad River Band of the Lake Superior Tribe of Chippewa Indians	WI	1	11%	1	14%	1	33%	1	50%	1	10%
Chickasaw Nation	OK	1	11%	1	14%	0	0%	0	0%	1	10%
Nez Perce Tribe	ID	1	11%	1	14%	0	0%	0	0%	1	10%
Quinault Indian Nation	WA	0	0%	1	14%	0	0%	0	0%	1	10%
Rocky Mountain Tribal Transportation Planners	MT	3	33%	0	0%	0	0%	0	0%	3	30%
Skagit River System Cooperative	WA	1	11%	1	14%	0	0%	0	0%	1	10%
Swinomish Indian Tribal Community	WA	1	11%	1	14%	1	33%	0	0%	1	10%
Yurok Tribe	CA	1	11%	1	14%	1	33%	1	50%	1	10%
Total		9	100%	7	100%	3	100%	2	100%	10	100%

Figure 18 shows the spatial distribution of the MCA areas of interest.

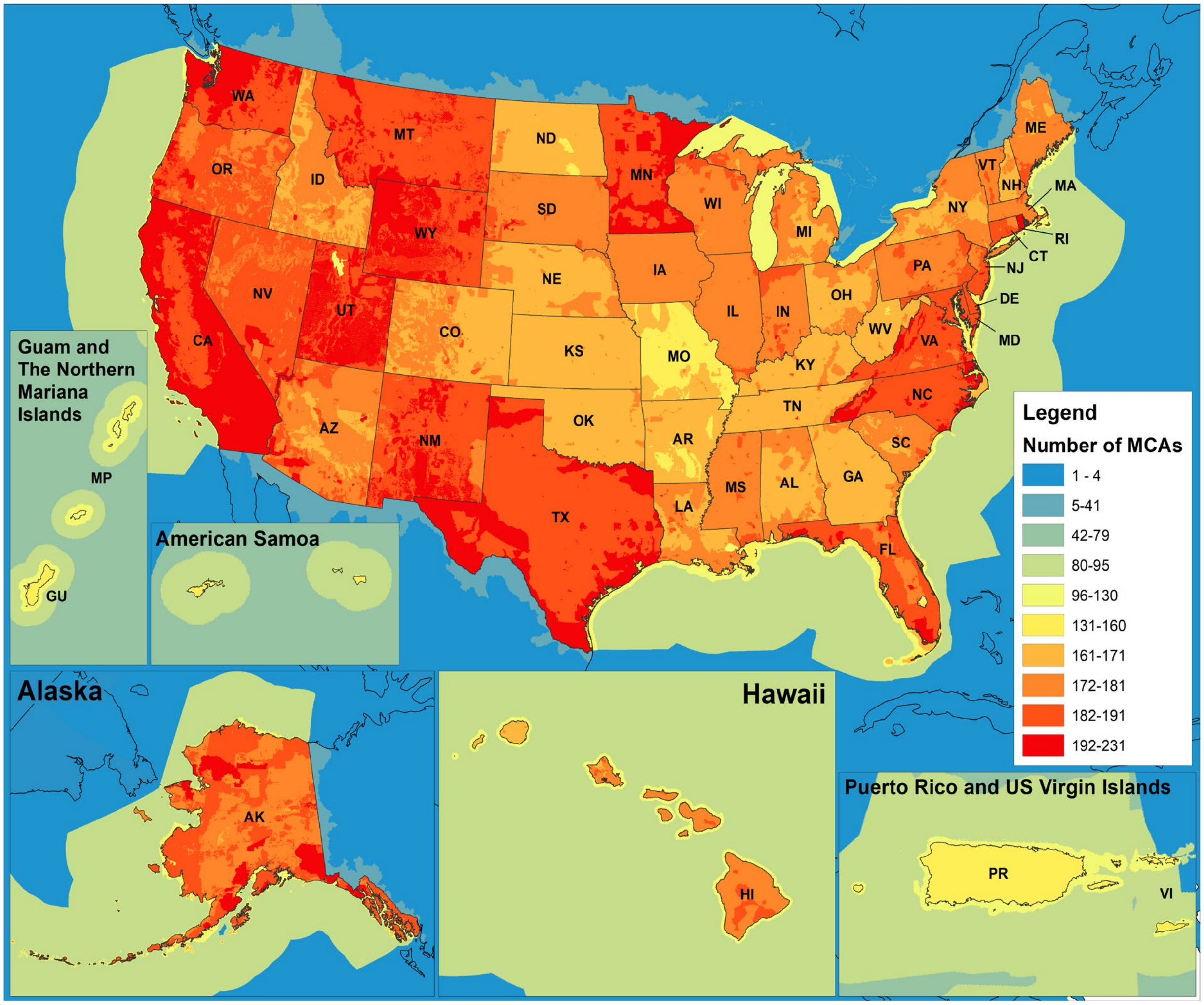


Figure 18. Map showing the spatial distribution of MCA areas of interest

5.2.4. Number of MCAs by Geography Type

Table 12 shows a summary of the MCAs by geography type. Note that a single MCA could include requirements for multiple geography types.

Table 12. Number of MCAs by geography type

Geography Type	Total MCAs	Percent of MCAs
Inland Topography	1,272	94%
Inland Bathymetry	831	61%
Nearshore Bathymetry	662	49%
Offshore Bathymetry	370	27%

5.2.7. Number of MCAs by Business Use

Table 13 shows the 30 Business Uses and the number of MCAs that listed that Business Use as its primary Business Use. Note that respondents could also list secondary and tertiary Business Uses in their MCA descriptions. Also note that 13 MCAs did not list a primary Business Use in the original online questionnaire response (i.e., before validation). After validation, all MCAs listed at least a primary Business Use. Note that details of the MCAs and reported benefits for the Business Uses are provided in Appendix E.

Table 13. Summary of MCAs by primary Business Use

Primary Business Uses	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
BU 01 - Water Supply and Quality	78	6%	68	8%	33	5%	17	5%	81	6%
BU 02 – Riverine Ecosystem Management	43	3%	41	5%	21	3%	7	2%	44	3%
BU 03 - Coastal Zone Management	57	4%	44	5%	64	10%	41	11%	66	5%
BU 04 - Forest Resources Management	50	4%	17	2%	9	1%	0	0%	50	4%
BU 05 – Rangeland Management	17	1%	3	0%	0	0%	0	0%	17	1%
BU 06 - Natural Resources Conservation	64	5%	41	5%	29	4%	17	5%	65	5%
BU 07 - Wildlife and Habitat Management	54	4%	45	5%	36	5%	25	7%	58	4%
BU 08 - Agriculture and Precision Farming	32	3%	15	2%	2	0%	2	1%	33	2%
BU 09 - Fisheries Management and Aquaculture	25	2%	30	4%	34	5%	24	6%	43	3%
BU 10 – Geologic Assessment and Hazard Mitigation	59	5%	32	4%	35	5%	21	6%	61	5%
BU 11 - Geologic Resource Mining and Extraction	24	2%	10	1%	6	1%	7	2%	25	2%

Primary Business Uses	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
BU 12 - Renewable Energy Resources	41	3%	16	2%	20	3%	18	5%	44	3%
BU 13 - Oil and Gas Resources	22	2%	12	1%	10	2%	8	2%	23	2%
BU 14 - Cultural Resources Preservation and Management	47	4%	28	3%	26	4%	17	5%	47	3%
BU 15 - Flood Risk Management	102	8%	73	9%	45	7%	21	6%	102	8%
BU 16 - Sea Level Rise and Subsidence	38	3%	27	3%	34	5%	16	4%	38	3%
BU 17 - Wildfire Management, Planning, and Response	31	2%	6	1%	2	0%	1	0%	31	2%
BU 18 - Homeland Security, Law Enforcement, Disaster Response, and Emergency Management	60	5%	41	5%	29	4%	15	4%	60	4%
BU 19 – Land Navigation and Safety	41	3%	24	3%	14	2%	4	1%	41	3%
BU 20 - Marine and Riverine Navigation and Safety	27	2%	40	5%	45	7%	33	9%	51	4%
BU 21 – Aviation Navigation and Safety	31	2%	9	1%	9	1%	4	1%	31	2%
BU 22 - Infrastructure and Construction Management	94	7%	68	8%	43	6%	11	3%	96	7%
BU 23 - Urban and Regional Planning	77	6%	41	5%	29	4%	8	2%	77	6%

Primary Business Uses	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
BU 24 - Health and Human Services	13	1%	6	1%	4	1%	2	1%	13	1%
BU 25 - Real Estate, Banking, Mortgage, and Insurance	15	1%	3	0%	4	1%	1	0%	15	1%
BU 26 - Education K-12 and Beyond, Basic Research	35	3%	31	4%	26	4%	19	5%	39	3%
BU 27 - Recreation	24	2%	22	3%	14	2%	5	1%	26	2%
BU 28 - Telecommunicati ons	29	2%	9	1%	9	1%	5	1%	30	2%
BU 29 - Military	13	1%	5	1%	6	1%	4	1%	14	1%
BU 30 - Maritime and Land Boundary Management	29	2%	24	3%	24	4%	17	5%	31	2%
Total	1,272	100%	831	100%	662	100%	370	100%	1,352	100%

5.3. Summary of Requirements

This section summarizes the requirements expressed by study respondents. Most of the requirements are broken out by geography type (Inland Topography, Inland Bathymetry, Nearshore Bathymetry, and Offshore Bathymetry). However, at the beginning and end of the questionnaire, respondents were asked questions that could apply to any geography.

5.3.1. Technology Agnostic Requirements

Respondents were initially asked a few questions about what they need to measure in 3D, the average geographic extent of their day-to-day work, and the smallest 3D feature of interest to their work. These were intended to be technology agnostic questions that could be used to evaluate requirements for emerging technologies going forward.

5.3.1.1. 3D Feature Types

Respondents were asked to describe the importance of features that need to be measured in 3D. The options provided for answering these questions in the online questionnaire were “Required,” “Highly desirable,” “Nice to have,” and “Not required.”

Table 14 and Figure 19 depict the importance of different features that users need to be able to measure in 3D ranked by the number of MCAs for which that feature type is "Required" for all geographies.

To account for responses other than "Required," the last column in Table 14 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

The greatest number of respondents reported that bare earth ground is needed (91%), followed by river and lake bottoms (51%), nearshore elevation (44%), tops of buildings, structures, objects (30%), and tops of vegetation (30% each). Using the weighted average score would change the order of the responses slightly but would not change the list of the top five. These responses indicate that the bare earth products in all geographies are needed along with the surface models that depict features above the surface.

Table 14. Requirements for features to be measured in 3D ranked by the number of MCAs for which that feature type is "Required" for all geographies

Requirements for Features to be Measured in 3D	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs	Weighted Average
Bare earth ground	1,215	31%	759	25%	578	22%	312	19%	1,224	91%	1,592
River/lake bottom	649	16%	677	23%	468	18%	275	16%	692	51%	1,139
Nearshore elevation (<10 m deep)	539	14%	489	16%	581	22%	341	20%	601	44%	926
Tops of buildings, structures, objects	407	10%	230	8%	189	7%	94	6%	409	30%	938
Tops of vegetation	397	10%	213	7%	150	6%	87	5%	399	30%	882
Ocean/sea bottom (>10 m deep)	289	7%	273	9%	332	13%	326	19%	334	25%	538
Subcanopy of vegetation/understory	154	4%	71	2%	50	2%	26	2%	154	11%	552
Sea surface	120	3%	105	4%	133	5%	92	6%	139	10%	343
Tops of submerged structures, objects	117	3%	99	3%	99	4%	78	5%	137	10%	496
Tops of submerged vegetation	54	1%	51	2%	48	2%	34	2%	60	4%	390
Other	26	1%	19	1%	14	1%	7	0%	27	2%	40

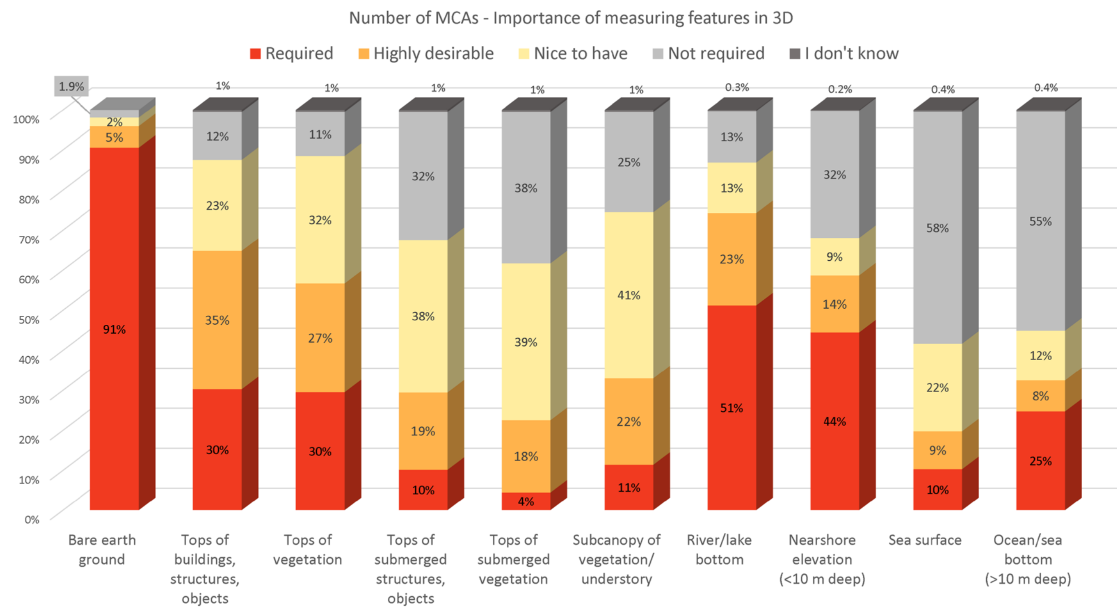


Figure 19. Requirements for features to be measured in 3D for all geographies

5.3.1.2. Geographic Extent

Respondents were asked about the geographic extent of their day-to-day work. Table 15 depicts the average geographic extent of day-to-day work areas reported by respondents across all geographies. The greatest number of respondents reported an average geographic extent of 1 sq. mi. – 49 sq. mi. (22%). The next most frequently reported average geographic extent is 1,000 – 24,999 sq. mi. (17%).

Table 15. Average geographic extent of day-to-day work across all geographies

Average Geographic Extent of Day-to-Day Work Area	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
Individual feature	45	4%	22	3%	19	3%	9	2%	45	3%
Less than 1 sq. mi.	189	15%	130	16%	111	17%	64	17%	210	16%
1 sq. mi. – 49 sq. mi.	280	22%	184	22%	136	21%	71	19%	294	22%
50 sq. mi. – 999 sq. mi.	175	14%	123	15%	107	16%	49	13%	185	14%
1,000 sq. mi. – 24,999 sq. mi.	227	18%	145	17%	108	16%	55	15%	235	17%
25,000 sq. mi. – 74,999 sq. mi.	139	11%	74	9%	50	8%	28	8%	143	11%

Average Geographic Extent of Day-to-Day Work Area	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
75,000 sq. mi. – 199,999 sq. mi.	60	5%	53	6%	43	7%	29	8%	73	5%
200,000 sq. mi. – 2 million sq. mi.	15	1%	12	1%	11	2%	9	2%	19	1%
Larger than 2 million sq. mi.	77	6%	47	6%	41	6%	31	8%	79	6%
No response	32	3%	21	3%	16	2%	12	3%	35	3%
Other	33	3%	20	2%	20	3%	13	4%	34	3%
Total	1,272	100%	831	100%	662	100%	370	100%	1,352	100%

5.3.1.3. Smallest 3D Features

Respondents were asked about the size of the smallest 3D feature they need to be able to discern in an elevation dataset.

Table 16 depicts the smallest feature of interest reported by respondents. The greatest number of respondents reported that they need to be able to discern small features (e.g., individual shrubs, trees, cars, mooring anchors, small docks, etc.) (43%). The next most frequently reported need is tied at survey-level features (e.g., signs, curbs, road lines, mailboxes, rocks, etc.) (24%) and large features (e.g., groups of trees, house, building, road, underwater wreck, large commercial pier, etc.) (24%).

Table 16. Smallest 3D feature of interest

Smallest 3D Feature of Interest	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
Survey-level features (e.g., sign, curb, road line, mailbox, rock, etc.)	311	24%	205	25%	145	22%	70	19%	324	24%

Smallest 3D Feature of Interest	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
Small features (e.g., individual shrub, tree, car, mooring anchor, small dock, etc.)	551	43%	366	44%	279	42%	165	45%	577	43%
Large features (e.g., groups of trees, house, building, road, underwater wreck, large commercial pier, etc.)	311	24%	172	21%	162	24%	91	25%	329	24%
Aggregated features (e.g., generalized landscapes, large areal patches of seagrass, coral reef, etc.)	63	5%	63	8%	56	8%	29	8%	83	6%
No response	26	2%	16	2%	13	2%	10	3%	29	2%
Other	10	1%	9	1%	7	1%	5	1%	10	1%
Total	1,272	100%	831	100%	662	100%	370	100%	1,352	100%

5.3.2. Inland Topography Requirements

Respondents were asked to characterize where they require 3D elevation data: inland land areas (Inland Topography); inland waters (Inland Bathymetry); nearshore/beaches including Great Lakes (topobathymetry and/or Nearshore Bathymetry); and offshore/Outer Continental Shelf/EEZ (Offshore Bathymetry). This section summarizes the requirements for 3D inland topographic data provided by the study respondents.

5.3.2.1. Acceptable Horizontal and Vertical Error

Respondents were asked about the amount of horizontal and vertical error that is acceptable in the 3D inland topographic data they use or need. Specifically, they were asked about the acceptable amount of Total Horizontal Uncertainty (THU) or Total Vertical Uncertainty (TVU) at the 95% confidence level.

Table 17 depicts the amount of horizontal error that is acceptable to respondents for Inland Topography. The greatest number of respondents (58%) reported a requirement for horizontal accuracy of “Up to 1 meter.” This level of horizontal accuracy is equivalent to that achievable by QL1 or QL2 lidar.

Table 17. Horizontal accuracy requirements at the 95% confidence level for Inland Topography

Horizontal Accuracy Requirements at the 95% Confidence Level for Inland Topography	Total MCAs	Percent of MCAs
Less than 20 cm	123	10%
Up to 30 cm	67	5%
Up to 40 cm	15	1%
Up to 50 cm	63	5%
Up to 60 cm	12	1%
Up to 80 cm	77	6%
Up to 1 m	739	58%
Up to 2 m	7	1%
Up to 5 m	8	1%
Up to 10 m	1	0%
Up to 20 m	2	0%
Greater than 20 m	0	0%
The best horizontal accuracy achievable for the vertical accuracy I need	123	10%
I don’t know	34	3%
Other (10 cm)	1	0%
No response	0	0%
Total	1,272	100%

Table 18 depicts the amount of vertical error that is acceptable to respondents for Inland Topography. The greatest number of respondents (61%) reported a requirement for vertical accuracy of “Up to 20 cm.” This level of vertical accuracy is equivalent to that achievable by QL1 or QL2 lidar.

Table 18. Vertical accuracy requirements at the 95% confidence level for Inland Topography

Vertical Accuracy Requirements at the 95% Confidence Level for Inland Topography	Total MCAs	Percent of MCAs
Less than 5 cm	109	9%
Up to 10 cm	265	21%
Up to 20 cm	774	61%

Vertical Accuracy Requirements at the 95% Confidence Level for Inland Topography	Total MCAs	Percent of MCAs
Up to 30 cm	37	3%
Up to 40 cm	4	0%
Up to 50 cm	12	1%
Up to 60 cm	2	0%
Up to 80 cm	3	0%
Up to 1 m	16	1%
Greater than 1 m	3	0%
I don't know	45	4%
Other (15 cm)	2	0%
No response	0	0%
Total	1,272	100%

5.3.2.2. Beach Profile

For areas near the coast, respondents were asked how far down the beach profile they need 3D inland topographic data. This question is only relevant in coastal areas.

Table 19 depicts how far down the beach profile 3D inland topographic data are needed. Of the 350 responses applicable to coastal areas, the greatest number reported a requirement for data below MLLW (41%). The next most frequently reported requirement is for data to MLLW (32%).

Table 19. Beach profile requirements for Inland Topography

Beach Profile Requirements for Inland Topography	Total MCAs	Percent of MCAs
To Mean Higher High Water (MHHW)	25	7%
To Mean High Water (MHW)	61	17%
To MLLW	112	32%
Below MLLW	142	41%
Other	10	3%
Total	350	100%

5.3.2.3. Quality Level

Respondents were asked what 3D inland topographic data Quality Level they require for the Inland Topography portion of their MCA.

Table 20 and Figure 20 depict the Quality Level requirements for Inland Topography. The greatest number of respondents reported a requirement for QL2 data (36%). The next most frequently reported requirement is for QL1 data (30%). Note however, that 60% of respondents require a higher Quality Level than the current 3DEP standard of QL2.

Table 20. Quality Level requirements for Inland Topography

Quality Level Requirements for Inland Topography	Total MCAs	Percent of MCAs
QL0HD	83	6%
QL0	96	7%
QL1HD	190	15%
QL1	381	30%
QL2	454	36%
QL3	3	0%
QL4	2	0%
QL5	0	0%
Don't know	8	1%
Cross sections meet needs	22	2%
Other/Mixed	33	3%
No response	0	0%
Total	1,272	100%

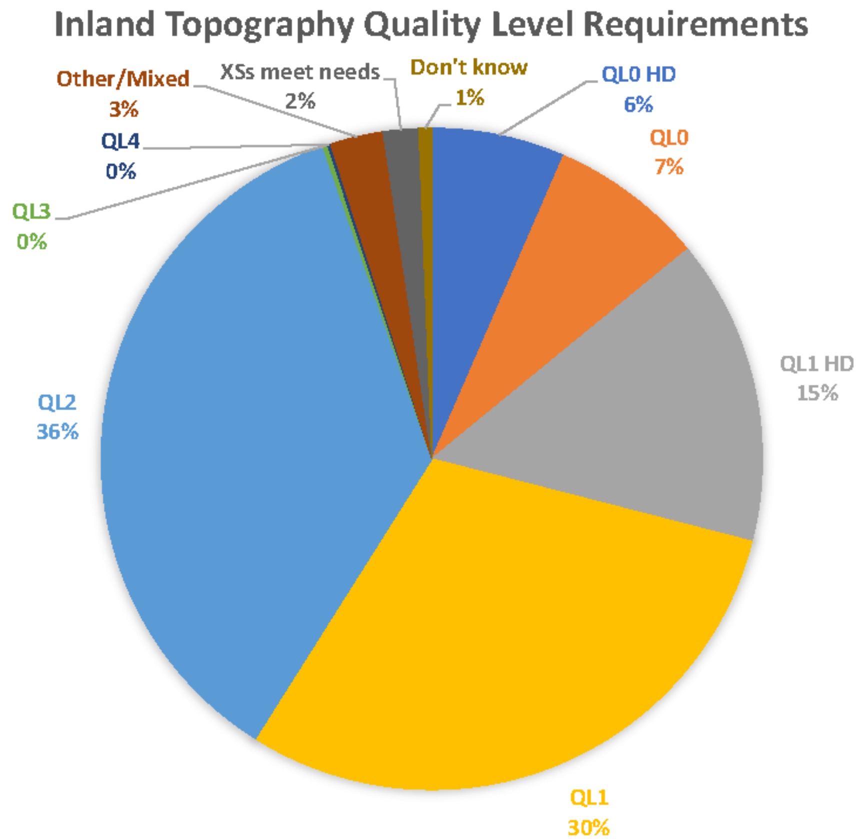


Figure 20. Quality Level requirements for Inland Topography

5.3.2.4. Update Frequency

Respondents were asked how frequently the 3D inland topographic data need to be updated to satisfy the requirements of the Inland Topography portion of their MCA.

Table 21 and Figure 21 depict the update frequency requirements for Inland Topography. The greatest number of respondents reported a requirement for 3D inland topographic data to be updated every 4-5 years (44%). The next most frequently reported requirement is for 3D inland topographic data to be updated every 2-3 years (22%). Note that 75% of respondents require an update frequency higher than the 8-year cycle currently envisioned for the 3DEP.

Table 21. Update frequency requirements for Inland Topography

Update Frequency Requirements for Inland Topography	Total MCAs	Percent of MCAs
Annually	109	9%
2-3 years	284	22%
4-5 years	560	44%
6-10 years	219	17%
>10 years	21	2%

Update Frequency Requirements for Inland Topography	Total MCAs	Percent of MCAs
Event driven only	32	3%
Don't know	6	0%
Other/Mixed	41	3%
No response	0	0%
Total	1,272	100%

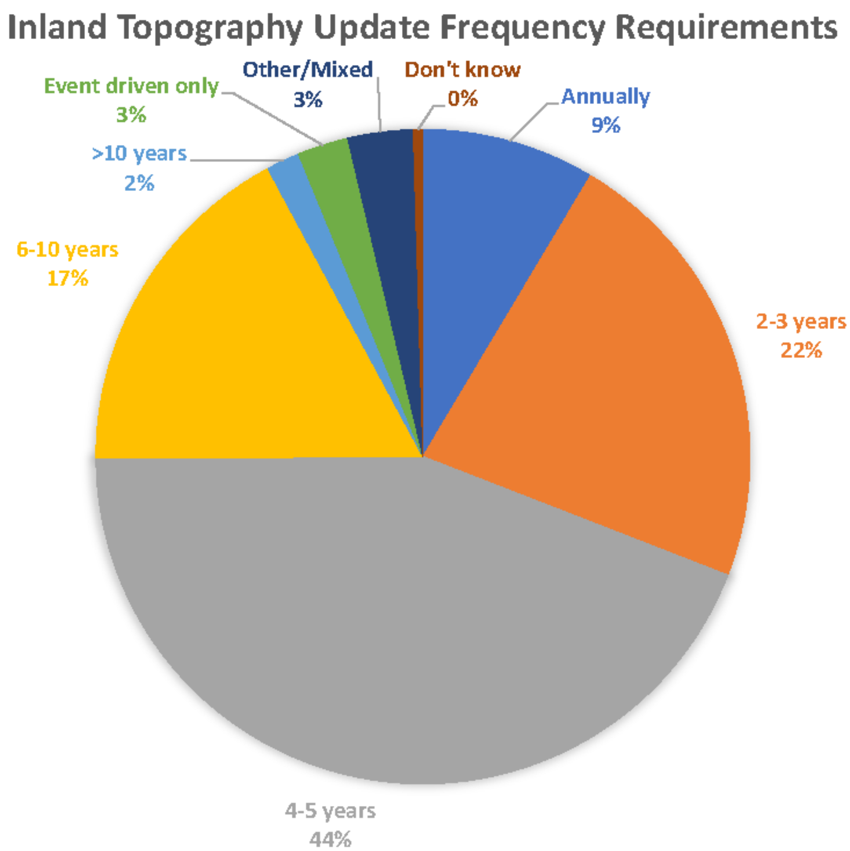


Figure 21. Update frequency requirements for Inland Topography

5.3.2.5. Hydrologic Processing

Respondents were asked about the importance of hydrologic processing to accomplishing their MCAs. Hydrologic processing is required to create a lidar-derived hydrologic DEM that represents the actual water flow surface for any hydrologic modeling. Hydro-flattening, hydro-enforcement, and hydro-conditioning are the three most common methods used to process lidar-derived DEMs for hydrologic modeling. The options provided for answering these questions in the online questionnaire were “Required,” “Highly desirable,” “Nice to have,” and “Not required.”

Hydro-Flattening

Hydro-flattening is performed to depict the bare-earth terrain as one could see and understand the terrain from an airplane flying overhead. Breaklines are used to force the surfaces of lakes and reservoirs to be flat, and rivers to be flat from bank to bank (perpendicular to the apparent flow centerline) while maintaining a downhill water surface gradient – either a smooth gradient or a stair-stepped gradient. Additionally, built features such as bridges and overpasses are removed from a bare-earth DEM because they are artificially elevated above the natural terrain.

Table 22 depicts the importance of hydro-flattening for Inland Topography. The greatest number of respondents reported that hydro-flattening is "Required." The next most frequently reported response is "Highly desirable."

Table 22. Hydro-flattening requirements for Inland Topography

Hydro-Flattening Requirements for Inland Topography	Total MCAs	Percent of MCAs
Required	464	36%
Highly desirable	382	30%
Nice to have	310	24%
Not required	106	8%
I don't know	9	1%
No response	1	0%

Hydro-Enforcement

Hydro-enforcement includes hydro-flattening but adds steps for treatment of narrower dual- and single-line drains and culverts to enforce the downward flow of water. Hydro-enforcement is required for hydrologic modeling and management of watersheds and for hydraulic modeling of floodplains. It is also used for stormwater management. Hydro-enforcement typically requires a large amount of manual processing.

Table 23 depicts the importance of hydro-enforcement for Inland Topography. The greatest number of respondents reported that hydro-enforcement is "Highly desirable." The next most frequently reported response is "Nice to have."

Table 23. Hydro-enforcement requirements for Inland Topography

Hydro-Enforcement Requirements for Inland Topography	Total MCAs	Percent of MCAs
Required	248	19%
Highly desirable	502	39%
Nice to have	369	29%
Not required	143	11%
I don't know	9	1%
No response	1	0%

Hydro-Conditioning
Hydro-conditioning is similar to hydro-enforcement, but with sinks filled to their pour points. Hydro-conditioning can be used as part of the hydro-enforcement process to identify where culverts may be needed. Filling (hydro-conditioning) un-drained depressions in the topographic DEM can reveal locations where downslope flow is impeded, typically road fills over culverts, and provide elevations where hydro-enforcement of the topographic DEMs are needed. Hydro-conditioning, or filling sinks, after culverts have been hydro-enforced can further refine the DEM for hydrologic and hydraulic modeling. After hydro-conditioning, the resulting flow of water is continuous across the entire surface and there are no areas of unconnected internal drainage.

Table 24 depicts the importance of hydro-conditioning for Inland Topography. The greatest number of respondents reported that hydro-conditioning is "Nice to have." The next most frequently reported response is "Highly desirable."

Table 24. Hydro-conditioning requirements for Inland Topography

Hydro-Conditioning Requirements for Inland Topography	Total MCAs	Percent of MCAs
Required	84	7%
Highly desirable	426	33%
Nice to have	560	44%
Not required	192	15%
I don't know	9	1%
No response	1	0%

5.3.2.6. Seamlessness within Inland Topography
Respondents were asked about the importance of seamless integration within the 3D inland topographic data to accomplishing their MCAs. Examples of data integration would be data collected at the same time (temporal integration) or data that spatially align between adjacent geographic areas (spatial integration). The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Note that questions were also asked about the importance of seamlessness between Inland Topography and Inland Bathymetry. Those results are presented in Tables 41 – 44. Additionally, questions were asked about the importance of seamlessness between topography, bathymetry, and topobathymetry (i.e., between Inland Topography and Inland Bathymetry and between Inland Topography and Nearshore Bathymetry). Those results are presented in Tables 75 – 77.

Spatial Integration
Seamless spatial integration refers to the integration of different datasets so that users cannot see seamlines between the two datasets (e.g., no obvious cliffs or voids where datasets join).

Table 25 depicts the importance of spatial seamlessness of DEMs and point clouds within inland topographic datasets. The greatest number of respondents reported that spatial seamlessness for DEMs is "Required" (58%). The next most frequently reported response for DEMs is "Highly desirable" (32%). The greatest number of respondents reported that spatial seamlessness for point clouds is "Required" (57%). The next most frequently reported response for point clouds is "Highly desirable" (32%).

Table 25. Requirements for spatial seamlessness within inland topographic datasets

Requirements for Spatial Seamlessness within Inland Topographic Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know	Percent I Don't Know
DEM Seamlessness	736	58%	412	32%	98	8%	19	1%	7	1%
Point Cloud Seamlessness	727	57%	408	32%	102	8%	28	2%	7	1%

Temporal Integration

Seamless temporal integration refers to the integration of multiple 3D datasets acquired at different times to reduce discontinuities between datasets acquired on different dates, and so that a user cannot see the differences. Temporal changes most commonly occur when the goal is to acquire 3D data under specific conditions, such as leaf-off conditions; early snowfall in the fall may cause data acquisition to be halted until the following spring, or leaf-on conditions in the spring may cause data acquisition to be halted until the following fall when leaf-off conditions return. Changes in water surface levels may be apparent due to the different time periods of collection.

Exceptions are routinely made when data acquisition flights are interrupted by unavoidable events such as natural disasters, e.g., wildfires, hurricanes, tornadoes, earthquakes or floods that change the 3D landscape. Other exceptions are with tidal waters that continuously change coastal shorelines. In the case of tidal variations, the temporal integration of datasets acquired even just an hour apart may not be seamless. Other temporal variations may also be unavoidable.

Table 26 depicts the importance of data collection under similar environmental conditions (e.g., similar low streamflow conditions, leaf off, leaf on, etc.) and the importance of data collection in the same acquisition season (e.g., Fall 2020), regardless of environmental conditions, within Inland Topography. The greatest number of respondents (49%) reported that temporal seamlessness for environmental conditions is “Highly desirable” (49%). The next most frequently reported response is “Required” (35%). The greatest number of respondents (46%) reported that temporal seamlessness for seasonal conditions is “Highly desirable” (46%). The next most frequently reported response is “Nice to have” (34%).

Table 26. Requirements for temporal seamlessness within inland topographic datasets

Requirements for Temporal Seamlessness within Inland Topographic Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know	Percent I Don't Know
Environmental Seamlessness	441	35%	624	49%	147	12%	53	4%	7	1%
Seasonal Seamlessness	137	11%	581	46%	436	34%	111	9%	7	1%

Acceptable Vertical Manipulation

When merging or joining one elevation dataset to another, there is normally a visible seamline between disparate elevation datasets because of: (1) temporal differences, (2) sensor differences, (3) different Quality Levels and accuracy standards, or (4) differences between topographic and bathymetric surfaces along the ever-changing tidal zone, for example.

There are many questions to be answered prior to determining whether or not it is actually desirable to manipulate elevation datasets either horizontally or vertically to make them seamless such as which dataset to hold as control, how far into a dataset do you make adjustments, what if the adjustment changes the accuracy of the dataset, etc.

Table 27 depicts the amount of vertical manipulation that is acceptable to respondents in order to achieve seamlessness within inland topographic datasets. The greatest number of respondents reported that the amount of acceptable vertical manipulation to achieve spatial seamlessness is "Up to the required TVU at the 95% confidence level" (50%). However, the next most frequently reported response is "I don't know" (23%), indicating that many respondents did not feel comfortable answering this question.

Table 27. Acceptable vertical manipulation to achieve seamlessness within inland topographic datasets

Acceptable Vertical Manipulation to Achieve Seamlessness within Inland Topographic Datasets	Total MCAs	Percent of MCAs
Up to the required TVU at the 95% confidence level	630	50%
Up to double the required TVU at the 95% confidence level	146	11%
Up to triple the required TVU at the 95% confidence level	22	2%
Whatever it takes to achieve seamlessness, including changes to the older, previously accepted dataset if it is proven to be less accurate than the newer	152	12%
I don't know	296	23%
None	3	0%
Other	20	2%
No response	3	0%
Total	1,272	100%

5.3.2.7. 3D Data Products

Respondents were asked about the importance of the following 3D inland topographic data products to accomplishing their MCAs. The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 28 depicts the inland topographic data products ranked by the number of MCAs for which that data product is "Required."

To account for responses other than "Required," the last column in Table 28 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

DEMs are the most frequently required data products, followed by Digital Terrain Models (DTM), ground control/ground truthing, classified point cloud data, and Digital Surface Models (DSM). Using the weighted average score would not change the order of the responses.

Table 28. Required inland topographic data products ranked by the number of MCAs for which that data product is "Required"

Required Inland Topographic Data Products	Total MCAs	Percent of MCAs	Weighted Average
DEM	1,055	83%	1,444
DTM	888	70%	1,314
Ground Control/Ground Truthing	530	42%	1,056
Classified Point Cloud	525	41%	1,049
DSM	358	28%	893
Breaklines for Hydro-Flattening	296	23%	808
Raw Point Cloud	228	18%	726
Breaklines for Hydro-Enforcement of Culverts	152	12%	668
Intensity Imagery	93	7%	581
Full Waveform	28	2%	280
Other	13	1%	23

5.3.2.8. Level of Integration with Other Data Products

Respondents were asked about the importance of integrating 3D inland topographic data with other datasets to accomplishing their MCAs. Examples of data integration would be data that align either spatially and/or temporally or attribute codes that are logically consistent.

The options provided for answering this question in the online questionnaire were “Required,” “Highly desirable,” “Nice to have,” and “Not required.”

Table 29 depicts the data products ranked by the number of MCAs for which integration with that dataset is “Required” for Inland Topography.

To account for responses other than “Required,” the last column in Table 29 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don’t know = 0.

Integration of 3D inland topographic data with aerial and/or satellite imagery is the most frequently required, followed by inland surface water features, bridges and culverts, wetlands, and Land Use/Land Cover data. Using the weighted average score would change the order of the responses slightly but would not change the list of the top five.

Table 29. Datasets required to be integrated with Inland Topography ranked by the number of MCAs for which integration is "Required"

Datasets Required to be Integrated with Inland Topography	Total MCAs	Percent of MCAs	Weighted Average
Aerial and/or Satellite Imagery	946	74%	1,396
Inland Surface Water Features	775	61%	1,225
Bridges/Culverts	563	44%	1,019
Wetlands	487	38%	1,015
Land Use/Land Cover	361	28%	964
Coastal and Riverine Structures	350	28%	856
Shorelines	250	20%	696
Landmark Features	160	13%	714
Cultural Resources	159	13%	601
Lowest Floor Elevation of Buildings	152	12%	520
Geologic and/or Seismic Data	89	7%	446
Other	12	1%	21

5.3.2.9. Derivative Products

Respondents were asked what derivative products they need to be able to generate from 3D inland topographic data to accomplish their MCAs. Respondents were able to select multiple data derivatives as being needed.

Table 30 depicts the data derivatives ranked by the number of MCAs for which that product is needed for Inland Topography. Contours are the most frequently required, followed by hillshades, slope maps, TINs, and hydrologic networks.

Table 30. Data derivatives needed from Inland Topography ranked by the number of MCAs for which that product is needed

Data Derivatives Needed from Inland Topography	Total MCAs	Percent of MCAs
Contours	518	41%
Hillshades	469	37%
Slope Maps	455	36%
TIN	385	30%
Hydrologic Networks	377	30%
Hydrologic Units	374	29%
Building Footprints	372	29%
Aspect Maps	348	27%
Hydrologic Flow Direction Grids	330	26%
Hydrologic Flow Accumulation Grids	307	24%

Data Derivatives Needed from Inland Topography	Total MCAs	Percent of MCAs
Cross Sections	300	24%
Height-Above-Ground-Maps	294	23%
Viewshed Maps	289	23%
Breaklines for Road Edge-of-Pavement	280	22%
Rugosity/Surface Roughness	223	18%
Curvature Maps	181	14%

5.3.2.10. National Sources of 3D Inland Topographic Data

Respondents were asked to indicate what national sources of inland topographic data are currently being used to address the elevation information needs of their MCA. Specifically, respondents were asked about their use of The National Map (TNM), Digital Coast, NCEI, Open Topography, state repositories, and other data sources.

Table 31 provides a summary of the current use of national repositories of 3D topography ranked by the number of MCAs for which that data source is used. The National Map is most frequently used as a source of 3D inland topographic data. However, it also reveals that study respondents widely use state and local repositories of 3D inland topographic data.

When "Other" data sources are used, 70 percent of the time it is locally developed and/or maintained elevation data. These locally collected and/or maintained data are either of higher resolution than the national datasets, having been collected for specific uses or sites, or improved or customized to serve the business needs of the MCA.

Table 31. Sources of inland topographic data ranked by the number of MCAs for which data are acquired there

Sources of Inland Topographic Data	Total MCAs	Percent of MCAs
The National Map	446	35%
State Repositories	390	31%
Other Sources	211	17%
Digital Coast	197	15%
Open Topography	128	10%
NOAA NCEI	106	8%

5.3.3. Inland Bathymetry Requirements

This section summarizes the requirements for 3D elevation data for Inland Bathymetry provided by the study respondents.

5.3.3.2. Feature Sizes

Respondents were asked how important the availability of Inland Bathymetry is for various feature sizes. The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 32 depicts the widths of rivers and streams with the number of MCAs for which the availability of Inland Bathymetry for that feature size is "Required."

To account for responses other than "Required," the last column in Table 32 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

Rivers and streams between 101 to 500 feet wide are the most frequently required, followed by river and stream widths of 51 to 100 feet, 10 to 50 feet, navigable channels, and 501 to 2,500 feet. Using the weighted average score would change the order of the responses but would not change the list of the top five.

Table 32. Requirements for Inland Bathymetry by river and stream width

Requirements for Inland Bathymetry by River and Stream Width	Total MCAs	Percent of MCAs	Weighted Average
Navigable channels (as defined by USACE)	376	45%	698
Less than 10 ft.	163	20%	503
10 - 50 ft.	392	47%	724
51 – 100 ft.	467	56%	763
101 – 500 ft.	479	58%	763
501 – 2,500 ft.	369	44%	673
Greater than 2,500 ft.	346	42%	641
Other	10	1%	18

Table 33 depicts the area of waterbodies with the number of MCAs for which the availability of Inland Bathymetry for that feature size is "Required."

To account for responses other than "Required," the last column in Table 33 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

Waterbodies of greater than 10 acres are the most frequently required, followed by waterbody areas of 5.1 to 10 acres, 2.1 to 5 acres, 1.1 to 2 acres, and 0.5 to 1 acre. Using the weighted average score would not change the order of the responses.

Table 33. Requirements for Inland Bathymetry by waterbody surface area

Requirements for Inland Bathymetry by Waterbody Surface Area	Total MCAs	Percent of MCAs	Weighted Average
Less than ½ acre	120	14%	436
½ - 1 acre	231	28%	600
1.1 – 2 acres	322	39%	665
2.1 – 5 acres	401	48%	716
5.1 – 10 acres	411	49%	732
Greater than 10 acres	481	58%	782
Other	9	1%	17

5.3.3.3. Acceptable Horizontal and Vertical Error

Respondents were asked about the amount of horizontal and vertical error that is acceptable in the 3D inland bathymetric data they use or need. Specifically, they were asked about the acceptable amount of THU or TVU at the 95% confidence level.

Table 34 depicts the amount of horizontal error that is acceptable to respondents for Inland Bathymetry. The greatest number of respondents (47%) reported a requirement for horizontal accuracy of "Up to 2 meters." This level of horizontal accuracy is equivalent to that achievable by QL0B or QL1B inland bathymetry.

Table 34. Horizontal accuracy requirements at the 95% confidence level for Inland Bathymetry

Horizontal Accuracy Requirements at the 95% Confidence Level for Inland Bathy	Total MCAs	Percent of MCAs
Less than 50 cm	87	10%
Up to 1 m	109	13%
Up to 2 m	387	47%
Up to 5 m	73	9%
Up to 10 m	20	2%
Up to 20 m	0	0%
Greater than 20 m	0	0%
The best horizontal accuracy achievable for the vertical accuracy I need	91	11%
I don't know	59	7%
Other	5	1%
No response	0	0%
Total	831	100%

Table 35 depicts the amount of vertical error that is acceptable to respondents for Inland Bathymetry. The greatest number of respondents (51%) reported a requirement for vertical accuracy of "Up to 30 cm." This level of vertical accuracy is equivalent to that achievable by QL0B or QL1B inland bathymetry.

Table 35. Vertical accuracy requirements at the 95% confidence level for Inland Bathymetry

Vertical Accuracy Requirements at the 95% Confidence Level for Inland Bathymetry	Total MCAs	Percent of MCAs
Less than 10 cm	90	11%
Up to 20 cm	79	10%
Up to 30 cm	421	51%
Up to 40 cm	105	13%
Up to 50 cm	37	4%
Up to 60 cm	4	0%
Up to 80 cm	1	0%
Up to 1 m	20	2%
Greater than 1 m	4	0%
I don't know	68	8%
Other	2	0%
No response	0	0%
Total	831	100%

5.3.3.4. Quality Level

Respondents were asked what 3D bathymetric data Quality Level they require for the Inland Bathymetry portion of their MCA.

Table 36 and Figure 22 depict the Quality Level requirements for Inland Bathymetry. The greatest number of respondents reported a requirement for QL0B data (39%). The next most frequently reported requirement is for QL1B data (26%).

Table 36. Quality Level requirements for Inland Bathymetry

Quality Level Requirements for Inland Bathymetry	Total MCAs	Percent of MCAs
QL0B	328	39%
QL1B	216	26%
QL2B	130	16%
QL3B	17	2%
QL4B	24	3%
Coarser data meet needs	5	1%
Don't know	40	5%

Quality Level Requirements for Inland Bathymetry	Total MCAs	Percent of MCAs
Cross sections meet needs	67	8%
Other/Mixed	4	0%
No response	0	0%
Total	831	100%

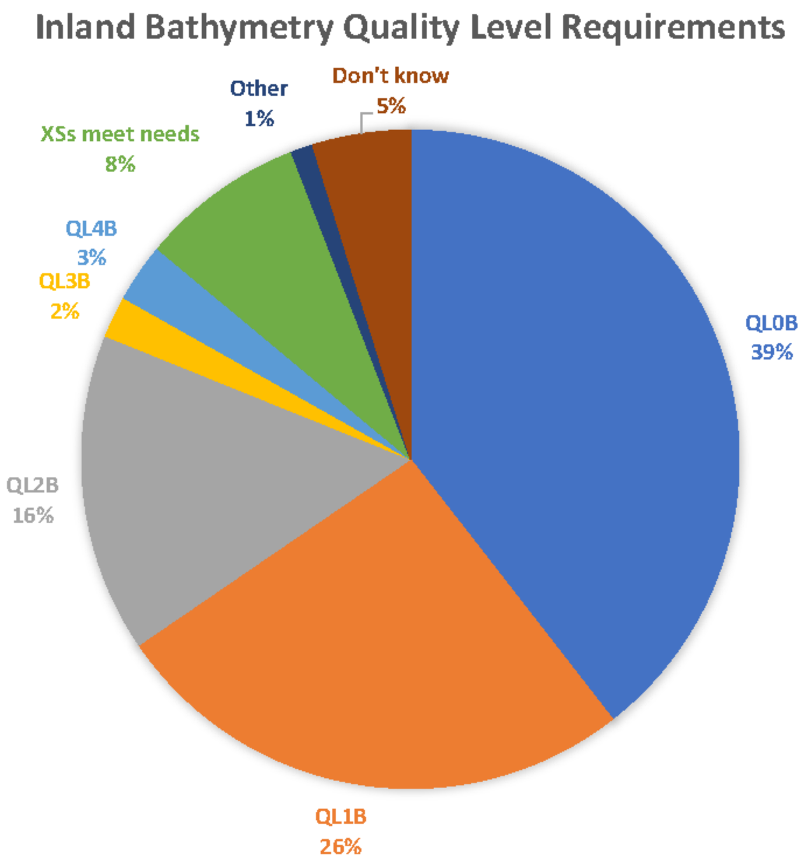


Figure 22. Quality Level requirements for Inland Bathymetry

5.3.3.5. Update Frequency

Respondents were asked how frequently the 3D bathymetric data need to be updated to satisfy the requirements of the Inland Bathymetry portion of their MCA.

Table 37 and Figure 23 depict the update frequency requirements for Inland Bathymetry. The greatest number of respondents reported a requirement for inland bathymetric data to be updated every 4-5 years (41%). The next most frequently reported requirement is for inland bathymetric data to be updated every 6-10 years (26%).

Table 37. Update frequency requirements for Inland Bathymetry

Update Frequency Requirements for Inland Bathymetry	Total MCAs	Percent of MCAs
Annually	29	3%
2-3 years	140	17%
4-5 years	338	41%
6-10 years	215	26%
>10 years	41	5%
Event driven only	39	5%
Don't know	24	3%
Other/Mixed	5	0%
No response	0	0%
Total	831	100%

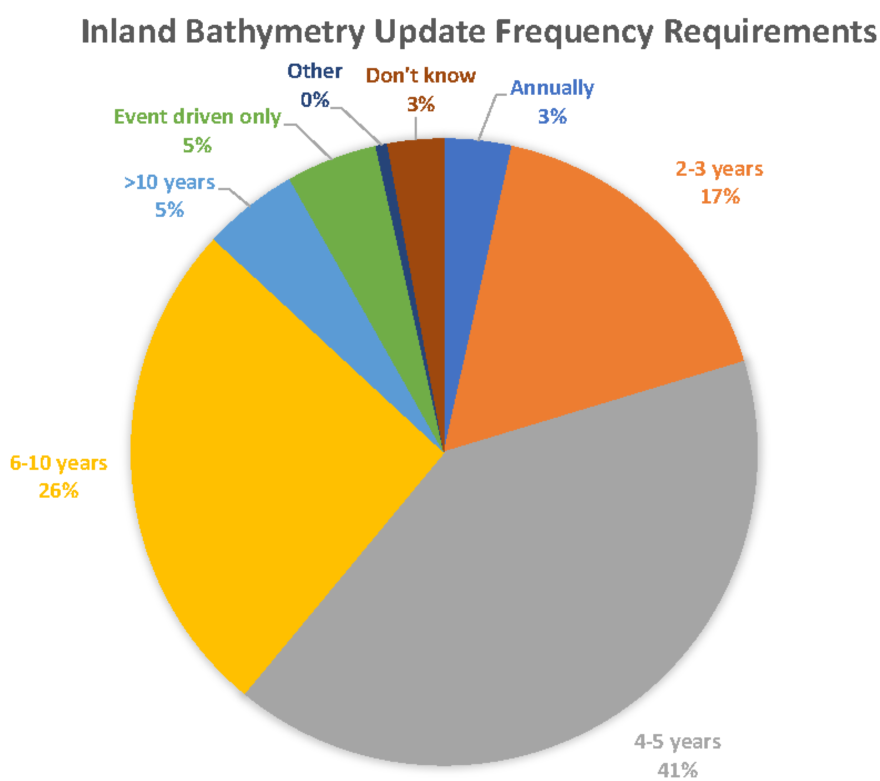


Figure 23. Update frequency requirements for Inland Bathymetry

5.3.3.6. Seamlessness within Inland Bathymetry

Respondents were asked about the importance of seamless integration within the 3D inland bathymetric data to accomplishing their MCAs. Examples of data integration would be data collected at the same time (temporal integration) or data that spatially align between adjacent geographic areas (spatial integration). The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Note that questions were also asked about the importance of seamlessness between Inland Topography and Inland Bathymetry. Those results are presented in Tables 41 – 44. Additionally, questions were asked about the importance of seamlessness between topography, bathymetry, and topobathymetry (i.e., between Inland Topography and Inland Bathymetry and between Inland Topography and Nearshore Bathymetry). Those results are presented in Tables 75 – 77.

Spatial Integration

Seamless spatial integration refers to the integration of different datasets so that users cannot see seamlines between the two datasets (e.g., no obvious cliffs or voids where datasets join).

Table 38 depicts the importance of spatial seamlessness of DEMs and point clouds within inland bathymetric datasets. The greatest number of respondents reported that spatial seamlessness for DEMs is "Required" (48%) The next most frequently reported response for DEMs is "Highly desirable" (32%). The greatest number of respondents reported that spatial seamlessness for point clouds is "Highly desirable" (49%). The next most frequently reported response for point clouds is "Required" (24%).

Table 38. Requirements for spatial seamlessness within inland bathymetric datasets

Requirements for Spatial Seamlessness within Inland Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know/No Response
DEM Seamlessness	398	48%	270	32%	111	13%	23	3%	29	3%
Point Cloud Seamlessness	197	24%	408	49%	127	15%	70	8%	29	3%

Temporal Integration

Seamless temporal integration refers to the integration of multiple 3D datasets acquired at different times to reduce discontinuities between datasets acquired on different dates, and so that a user cannot see the differences. Temporal changes most commonly occur when the goal is to acquire 3D data under specific conditions, such as leaf-off conditions; early snowfall in the fall may cause data acquisition to be halted until the following spring, or leaf-on conditions in the spring may cause data acquisition to be halted until the following fall when leaf-off conditions return. Changes in water surface levels may be apparent due to the different time periods of collection.

Exceptions are routinely made when data acquisition flights are interrupted by unavoidable events such as natural disasters, e.g., wildfires, hurricanes, tornadoes, earthquakes or floods that change the 3D landscape. Other exceptions are with tidal waters that continuously change coastal shorelines. In the case of tidal variations, the temporal integration of datasets acquired even just an hour apart may not be seamless. Other temporal variations may also be unavoidable.

Table 39 depicts the importance of data collection under similar environmental conditions (e.g., similar low streamflow conditions, turbidity, or other weather conditions, etc.) and the importance of data collection in the same acquisition season (e.g., Fall 2020), regardless of environmental conditions, within inland bathymetric datasets. The greatest number of respondents (49%) reported that temporal seamlessness for environmental conditions is "Highly desirable." The next most frequently reported response for environmental conditions is "Required" (21%). The greatest number of respondents (37%) reported that temporal seamlessness for seasonal conditions is "Highly desirable." The next most frequently reported response for seasonal conditions is "Nice to have" (35%).

Table 39. Requirements for temporal seamlessness within inland bathymetric datasets

Requirements for Temporal Seamlessness within Inland Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know/No Response
Environmental Seamlessness	174	21%	437	53%	125	15%	66	8%	29	3%
Seasonal Seamlessness	75	9%	308	37%	290	35%	129	16%	29	3%

Acceptable Vertical Manipulation

When merging or joining one elevation dataset to another, there is normally a visible seamline between disparate elevation datasets because of: (1) temporal differences, (2) sensor differences, (3) different Quality Levels and accuracy standards, or (4) differences between topographic and bathymetric surfaces along the ever-changing tidal zone, for example.

There are many questions to be answered prior to determining whether or not it is actually desirable to manipulate elevation datasets either horizontally or vertically to make them seamless such as which dataset to hold as control, how far into a dataset do you make adjustments, what if the adjustment changes the accuracy of the dataset, etc.

Table 40 depicts the amount of vertical manipulation that is acceptable to respondents in order to achieve seamlessness within inland bathymetric datasets. The greatest number of respondents (46%) reported that the amount of acceptable vertical manipulation to achieve spatial seamlessness is "Up to the required TVU at the 95% confidence level." However, the next most frequently reported response is “I don’t know” (27%), indicating that many respondents did not feel comfortable answering this question.

Table 40. Acceptable vertical manipulation to achieve seamlessness within inland bathymetric datasets

Acceptable Vertical Manipulation to Achieve Seamlessness within Inland Bathymetric Datasets	Total MCAs	Percent of MCAs
Up to the required TVU at the 95% confidence level	381	46%
Up to double the required TVU at the 95% confidence level	86	10%
Up to triple the required TVU at the 95% confidence level	33	4%
Whatever it takes to achieve seamlessness, including changes to the older, previously accepted dataset if it is proven to be less accurate than the newer	95	11%
I don’t know	222	27%
None	2	0%
Other	5	1%
No response	7	1%
Total	831	100%

5.3.3.7. Seamlessness between Inland Topography and Inland Bathymetry

Respondents were asked about the importance of seamless integration between inland topographic and inland bathymetric data to accomplishing their MCAs. Examples of data integration would be data collected at the same time (temporal integration) or data that spatially align between adjacent geographic areas (spatial integration). The options provided for answering this question in the online questionnaire were “Required,” “Highly desirable,” “Nice to have,” and “Not required.”

Note that questions were also asked about seamlessness within geography types (e.g., within Inland Topography) and between topography, bathymetry, and topobathymetry. Those results are presented in Tables 25 – 27 (for Inland Topography), Tables 38 – 40 (for Inland Bathymetry), Tables 56 – 58 (for Nearshore Bathymetry), Tables 68 – 70 (for Offshore Bathymetry), and Tables 70 – 72 (for topography, bathymetry, and topobathymetry).

Table 41 depicts the importance of spatial seamlessness in general between Inland Topography and Inland Bathymetry. The greatest number of respondents reported that spatial seamlessness is "Highly desirable" (49%) The next most frequently reported response is "Required" (27%).

Table 41. Requirements for spatial seamlessness of DEMs between inland topographic and inland bathymetric datasets

Requirements for Seamlessness between Inland Topographic and Inland Bathymetric Datasets	Total MCAs	Percent of MCAs
Required	226	27%
Highly desirable	411	49%
Nice to have	114	14%
Not required	10	1%
I don't know	26	3%
No response	44	5%

Spatial Integration

Table 42 depicts the importance of spatial seamlessness of DEMs and point clouds between Inland Topography and Inland Bathymetry. The greatest number of respondents reported that spatial seamlessness for DEMs is "Highly desirable" (39%) The next most frequently reported response for DEMs is "Required" (34%). The greatest number of respondents reported that spatial seamlessness for point clouds is "Highly desirable" (48%). The next most frequently reported response for point clouds is "Required" (20%).

Table 42. Requirements for spatial seamlessness between inland topographic and inland bathymetric datasets

Requirements for Spatial Seamlessness between Inland Topographic and Inland Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know
DEM Seamlessness	284	34%	328	39%	122	15%	31	4%	66	8%
Point Cloud Seamlessness	170	20%	397	48%	142	17%	56	7%	66	8%

Temporal Integration

Table 43 depicts the importance of data collection under similar environmental conditions (e.g., similar low streamflow conditions, turbidity, or other weather conditions, etc.) and the importance of data collection in the same acquisition season (e.g., Fall 2020), regardless of environmental conditions, between inland topographic and inland bathymetric datasets. The greatest number of respondents (50%) reported that temporal seamlessness for environmental conditions is "Highly desirable." The next most frequently reported response for environmental conditions is "Required"

(18%). The greatest number of respondents (39%) reported that temporal seamlessness for seasonal conditions is "Highly desirable." The next most frequently reported response for seasonal conditions is "Nice to have" (31%).

Table 43. Requirements for temporal seamlessness between inland topographic and inland bathymetric datasets

Requirements for Temporal Seamlessness between Inland Topographic and Inland Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know/No Response
Environmental Seamlessness	148	18%	417	50%	139	17%	61	7%	66	8%
Seasonal Seamlessness	83	10%	324	39%	256	31%	102	12%	66	8%

Acceptable Vertical Manipulation

Table 44 depicts the amount of vertical manipulation that is acceptable to respondents in order to achieve seamlessness within inland bathymetric datasets. The greatest number of respondents (44%) reported that the amount of acceptable vertical manipulation to achieve spatial seamlessness is "Up to the required TVU at the 95% confidence level." However, the next most frequently reported response is "I don't know" (26%), indicating that many respondents did not feel comfortable answering this question.

Table 44. Acceptable vertical manipulation to achieve seamlessness between inland topographic and inland bathymetric datasets

Acceptable Vertical Manipulation to Achieve Seamlessness between Inland Topographic and Inland Bathymetric Datasets	Total MCAs	Percent of MCAs
Up to the required TVU at the 95% confidence level	367	44%
Up to double the required TVU at the 95% confidence level	94	11%
Up to triple the required TVU at the 95% confidence level	17	2%
Whatever it takes to achieve seamlessness, including changes to the older, previously accepted dataset if it is proven to be less accurate than the newer	92	11%
I don't know	215	26%
None	0	0%
Other	6	1%
No response	40	5%
Total	831	100%

5.3.3.8. 3D Data Products

Respondents were asked about the importance of the following 3D data products to accomplishing their MCAs. The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 45 depicts the data products ranked by the number of MCAs for which that data product is "Required" for Inland Bathymetry.

To account for responses other than "Required," the last column in Table 45 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

DEMs are the most frequently required, followed by DTMs, ground control/ground truthing, classified point cloud data, and DSMs. Using the weighted average score would change the order of the responses slightly but would not change the list of the top five.

Table 45. Required inland bathymetric data products ranked by the number of MCAs for which that data product is "Required"

Required Inland Bathymetric Data Products	Total MCAs	Percent of MCAs	Weighted Average
DEM	635	76%	881
DTM	307	37%	669
Ground Control/Ground Truthing	241	29%	599
Classified Point Cloud	211	25%	523
DSM	178	21%	542
Breaklines for Hydro-flattening	154	19%	463
Raw Point Cloud	111	13%	390
Intensity Imagery/Sidescan Imagery	55	7%	353
BAG	37	4%	266
Edited/Cube XYZ	19	2%	227
Full Waveform	17	2%	178
Other	5	1%	6

5.3.3.9. Level of Integration with Other Data Products

Respondents were asked about the importance of integrating 3D inland bathymetric data with other datasets to accomplishing their MCAs. Examples of data integration would be data that align either spatially and/or temporally or attribute codes that are logically consistent.

The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 46 depicts the data products ranked by the number of MCAs for which integration with that data product is "Required" for Inland Bathymetry.

To account for responses other than "Required," the last column in Table 46 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

Integration of 3D inland bathymetric data with inland surface water features is the most frequently required, followed by aerial and/or satellite imagery, shorelines, bridges, and coastal and riverine structures. Using the weighted average score would change the order of the responses slightly but would not change the list of the top five.

Table 46. Datasets required to be integrated with Inland Bathymetry ranked by the number of MCAs for which integration is "Required"

Datasets Required to be Integrated with Inland Bathymetry	Total MCAs	Percent of MCAs	Weighted Average
Inland Surface Water Features	528	64%	826
Aerial and/or Satellite Imagery	476	57%	800
Shorelines	306	37%	664
Bridges	287	35%	656
Coastal and Riverine Structures	284	34%	654
Wetlands	248	30%	651
Land Use/Land Cover	184	22%	567
Landmark Features	100	12%	442
Geologic and/or Seismic Data	64	8%	319
Cultural Resources	42	5%	325
Other	0	0%	1

5.3.3.10. Derivative Products

Respondents were asked what derivative products they need to be able to generate from 3D inland bathymetric data to accomplish their MCAs. Respondents were able to select multiple data derivatives as being needed.

Table 47 depicts the data derivatives ranked by the number of MCAs for which that product is needed for Inland Bathymetry. Contours are the most frequently required, followed by cross sections, TINs, hydrologic networks, and hillshades.

Table 47. Data derivatives needed from Inland Bathymetry ranked by the number of MCAs for which that product is needed

Data Derivatives Needed from Inland Bathymetry	Total MCAs	Percent of MCAs
Contours	306	37%
Cross Sections	206	25%
TIN	202	24%
Hydrologic Networks	200	24%
Hillshades	188	23%
Hydrologic Units	174	21%
Hydrologic Flow Direction Grids	166	20%
Slope Map	160	19%
Hydrologic Flow Accumulation Grids	151	18%
Aspect Maps	95	11%
Rugosity/Surface Roughness	94	11%
Height-Above-Ground-Maps	80	10%
Curvature Maps	75	9%
Viewshed Maps	60	7%
Building Footprints	57	7%
Breaklines for Road Edge-of-Pavement	48	6%

5.3.3.11. National Sources of 3D Inland Bathymetric Data

Respondents were asked to indicate what national sources of inland bathymetric data are currently being used to address the elevation information needs of their MCA. Specifically, respondents were asked about their use of the Digital Coast, NCEI, NOAA nautical charts, USACE inland electronic navigation charts, USGS Inland Waters of the U.S. map server, USGS data series, state repositories, and other data sources.

Table 48 provides a summary of the current use of national repositories of 3D inland bathymetry ranked by the number of MCAs for which that data source is used. The greatest number of respondents reported that the inland bathymetric data they need are not currently available. The Digital Coast and NOAA nautical charts are reported as the most frequently used sources of what little inland bathymetry is available. It also reveals that state and local repositories of inland bathymetry are important to study respondents.

When "Other" data sources are used, 71 percent of the time it is locally developed and/or maintained elevation data. These locally collected and/or maintained data are either of higher resolution than the national datasets, having been collected for specific uses or sites, or improved or customized to serve the business needs of the MCA.

Table 48. Sources of inland bathymetric data ranked by the number of MCAs for which data are acquired there

Sources of Inland Bathymetric Data	Total MCAs	Percent of MCAs
Data that Meet My Needs Is Not Available	138	17%
Digital Coast	130	16%
NOAA Nautical Charts	118	14%
Other	108	13%
State Repositories	101	12%
USACE Inland Electronic Navigation Charts	100	12%
USGS Data Series	96	12%
NOAA NCEI	93	11%
USGS Inland Waters Map Server	48	6%

5.3.4. Nearshore Bathymetry Requirements

This section summarizes the requirements for 3D elevation data for Nearshore Bathymetry provided by the study respondents.

5.3.4.1. Acceptable Horizontal and Vertical Error

Respondents were asked about the amount of horizontal and vertical error that is acceptable in the 3D nearshore bathymetric data they use or need. Specifically, they were asked about the acceptable amount of THU or TVU at the 95% confidence level.

Table 49 depicts the amount of horizontal error that is acceptable to respondents for Nearshore Bathymetry. The greatest number of respondents (40%) reported a requirement for horizontal accuracy of "Up to 2 meters." This level of horizontal accuracy is equivalent to that achievable by QL0B or QL1B nearshore bathymetric data.

Table 49. Horizontal accuracy requirements at the 95% confidence level for Nearshore Bathymetry

Horizontal Accuracy Requirements at the 95% Confidence Level for Nearshore Bathymetry	Total MCAs	Percent of MCAs
Less than 50 cm	67	10%
Up to 1 m	91	14%
Up to 2 m	264	40%
Up to 5 m	121	18%
Up to 10 m	8	1%
Up to 20 m	0	0%
Greater than 20 m	2	0%
The best horizontal accuracy achievable for the vertical accuracy I need	58	9%

Horizontal Accuracy Requirements at the 95% Confidence Level for Nearshore Bathymetry	Total MCAs	Percent of MCAs
I don't know	46	7%
Other	5	1%
Total	662	100%

Table 50 depicts the amount of vertical error that is acceptable to respondents for Nearshore Bathymetry. The greatest number of respondents (43%) reported a requirement for vertical accuracy of "Up to 30 cm." This level of vertical accuracy is equivalent to that achievable by QL0B or QL1B nearshore bathymetric data.

Table 50. Vertical accuracy requirements at the 95% confidence level for Nearshore Bathymetry

Vertical Accuracy Requirements at the 95% Confidence Level for Nearshore Bathymetry	Total MCAs	Percent of MCAs
Less than 10 cm	64	10%
Up to 20 cm	56	8%
Up to 30 cm	287	43%
Up to 40 cm	144	22%
Up to 50 cm	28	4%
Up to 60 cm	2	0%
Up to 80 cm	1	0%
Up to 1 m	24	4%
Greater than 1 m	2	0%
I don't know	52	8%
Other	2	0%
No response	0	0%
Total	662	100%

5.3.4.2. Distance Onshore and Beach Profile

For areas near the coast, respondents were asked how far onshore and how far down the beach profile they need 3D nearshore bathymetric data.

Table 51 depicts how far onshore 3D nearshore bathymetric data are needed. Of the 324 applicable responses, the greatest number reported a requirement for data to cover the coastal uplands (15%). The next most frequently reported requirement is for data to cover the beach slope (13%). However, there is a wide spread of requirements and no one requirement received a significantly higher percentage.

Table 51. Onshore data collection requirements for Nearshore Bathymetry

Onshore Data Collection Requirements for Nearshore Bathymetry	Total MCAs	Percent of MCAs
500 m inland	28	9%
1 km inland	31	10%
>1 km inland	29	9%
To cover the beach slope	42	13%
To cover the coastal uplands	49	15%
To the fall line	30	9%
To MHHW	30	9%
To MHW	29	9%
To MLLW	17	5%
None. I do not need onshore data.	6	2%
Other	19	6%
Don't know	7	2%
No response	7	2%
Total	324	100%

Table 52 depicts how far down the beach profile 3D nearshore bathymetric data are needed. Of the 324 applicable responses, the greatest number reported a requirement for data below MLLW (50%). The next most frequently reported requirement is for data to MLLW (19%).

Table 52. Beach profile requirements for Nearshore Bathymetry

Beach Profile Requirements for Nearshore Bathymetry	Total MCAs	Percent of MCAs
To MHHW	21	6%
To MHW	27	8%
To MLLW	62	19%
Below MLLW	163	50%
Other	21	6%
None	16	5%
Don’t know	8	2%
No response	6	2%
Total	324	100%

5.3.4.3. Quality Level

Respondents were asked what 3D bathymetric data Quality Level they require for the Nearshore Bathymetry portion of their MCA.

Table 53 and Figure 24 depict the Quality Level requirements for Nearshore Bathymetry. The greatest number of respondents (34%) reported a requirement for QL0B data. The next most frequently reported requirement is for QL1B data (24%).

Table 53. Quality Level requirements for Nearshore Bathymetry

Quality Level Requirements for Nearshore Bathymetry	Total MCAs	Percent of MCAs
QL0B	226	34%
QL1B	158	24%
QL2B	150	23%
QL3B	25	4%
QL4B	18	3%
Coarser data meet needs	2	0%
Don't know	42	6%
Cross sections meet needs	37	5%
Other/Mixed	4	1%
No response	0	0%
Total	662	100%

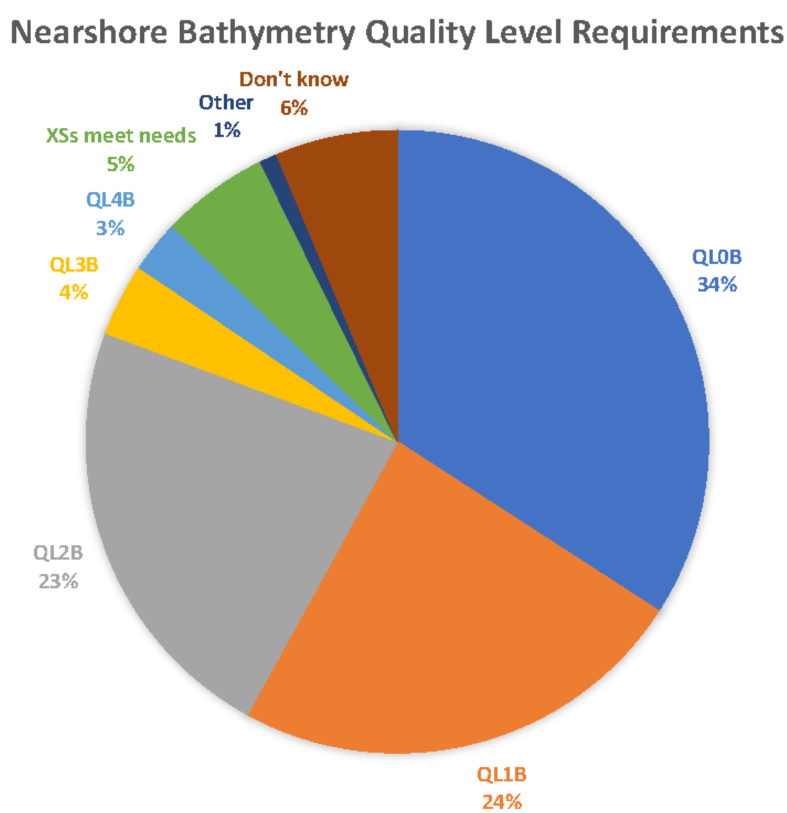


Figure 24. Nearshore Bathymetry Quality Level Requirements

5.3.4.4. Update Frequency

Respondents were asked how frequently the 3D bathymetric data need to be updated to satisfy the requirements of the nearshore portion of their MCA.

Table 54 and Figure 25 depict the update frequency requirements for Nearshore Bathymetry. The greatest number of respondents (36%) reported a requirement for nearshore bathymetric data to be updated every 4-5 years. The next most frequently reported requirement is for nearshore bathymetric data to be updated every 2-3 years (29%).

Table 54. Update frequency requirements for Nearshore Bathymetry

Update Frequency Requirements for Nearshore Bathymetry	Total MCAs	Percent of MCAs
Annually	40	6%
2-3 years	191	29%
4-5 years	236	36%
6-10 years	112	17%
>10 years	16	2%
Event driven only	29	4%
Don't know	28	4%
Other/Mixed	9	2%
No response	1	0%
Total	662	100%

Nearshore Bathymetry Update Frequency Requirements

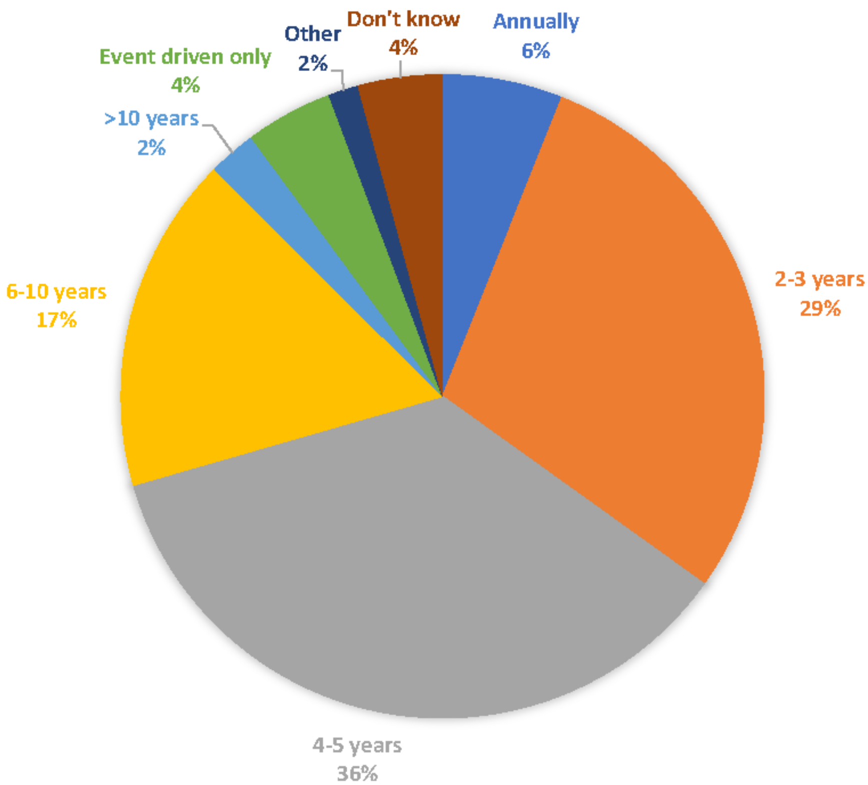


Figure 25. Nearshore Bathymetry Update Frequency Requirements

5.3.4.5. Tide Correction

Respondents were asked if there is a requirement for the 3D nearshore bathymetric data to be tide corrected to meet the needs of the Nearshore Bathymetry portion of their MCA.

Table 55 depicts the requirements for tide correction for 3D nearshore bathymetric data. Of the 324 applicable responses, the greatest number with a requirement for tide correction reported a requirement for tide correction using MLLW. However, an almost equal number said they do not know what their requirement for tide correction is. And a significant number reported no requirement for tide correction.

Table 55. Tide correction requirements for Nearshore Bathymetry

Tide Correction Requirements for Nearshore Bathymetry	Total MCAs	Percent of MCAs
No requirement for tide correction	60	19%
Tide correction using MHW	59	18%
Tide correction using Mean Sea Level (MSL)	33	10%
Tide correction using MLLW	67	21%
NAVD88	10	3%
Other	17	5%

Tide Correction Requirements for Nearshore Bathymetry	Total MCAs	Percent of MCAs
I don't know	71	22%
No response	7	2%
Total	324	100%

5.3.4.6. Seamlessness within Nearshore Bathymetry

Respondents were asked about the importance of seamless integration within the 3D nearshore bathymetric data to accomplishing their MCAs. Examples of data integration would be data collected at the same time (temporal integration) or data that spatially align between adjacent geographic areas (spatial integration). The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Note that questions were also asked about the importance of seamlessness between topography, bathymetry, and topobathymetry (i.e., between Inland Topography and Nearshore Bathymetry and between Nearshore Bathymetry and Offshore Bathymetry). Those results are presented in Tables 75 – 77.

Spatial Integration

Seamless spatial integration refers to the integration of different datasets so that users cannot see seamlines between the two datasets (e.g., no obvious cliffs or voids where datasets join).

Table 56 depicts the importance of spatial seamlessness of DEMs and point clouds within Nearshore Bathymetry. The greatest number of respondents reported that spatial seamlessness for DEMs is "Highly desirable" (44%) The next most frequently reported response for DEMs is "Required" (37%). The greatest number of respondents reported that spatial seamlessness for point clouds is "Highly desirable" (52%). The next most frequently reported response for point clouds is "Required" (22%).

Table 56. Requirements for spatial seamlessness within nearshore bathymetric datasets

Requirements for Spatial Seamlessness within Nearshore Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know/No Response
DEM Seamlessness	248	37%	288	44%	86	13%	16	2%	24	4%
Point Cloud Seamlessness	147	22%	343	52%	115	17%	33	5%	24	4%

Temporal Integration

Seamless temporal integration refers to the integration of multiple 3D datasets acquired at different times to reduce discontinuities between datasets acquired on different dates, and so that a user cannot see the differences. Temporal changes most commonly occur when the goal is to acquire 3D data under specific conditions, such as leaf-off conditions; early snowfall in the fall may cause data acquisition to be halted until the following spring, or leaf-on conditions in the spring may cause data acquisition to be halted until the following fall when leaf-off conditions return. Changes in water surface levels may be apparent due to the different time periods of collection.

Exceptions are routinely made when data acquisition flights are interrupted by unavoidable events such as natural disasters, e.g., wildfires, hurricanes, tornadoes, earthquakes or floods that change the 3D landscape. Other exceptions are with tidal waters that continuously change coastal shorelines. In the case of tidal variations, the temporal integration of datasets acquired even just an hour apart may not be seamless. Other temporal variations may also be unavoidable.

Table 57 depicts the importance of data collection under similar environmental conditions (e.g., similar low streamflow conditions, turbidity, or other weather conditions, etc.) and the importance of data collection in the same acquisition season (e.g., Fall 2020), regardless of environmental conditions within nearshore bathymetric datasets. The greatest number of respondents (47%) reported that temporal seamlessness for environmental conditions is “Highly desirable.” The next most frequently reported response for environmental conditions is “Nice to have” (23%). The greatest number of respondents (37%) reported that temporal seamlessness for seasonal conditions is “Highly desirable.” The next most frequently reported response for seasonal conditions is “Nice to have” (36%).

Table 57. Requirements for temporal seamlessness within nearshore bathymetric datasets

Requirements for Temporal Seamlessness within Nearshore Bathymetric Datasets	**Required**	**Percent Required**	**Highly Desirable**	**Percent Highly Desirable**	**Nice to Have**	**Percent Nice to Have**	**Not Required**	**Percent Not Required**	**I Don't Know/No Response**	**Percent I Don't Know/No Response**
Environmental Seamlessness	137	21%	310	47%	149	23%	42	6%	24	4%
Seasonal Seamlessness	94	14%	242	37%	238	36%	64	10%	24	4%

Acceptable Vertical Manipulation

When merging or joining one elevation dataset to another, there is normally a visible seamline between disparate elevation datasets because of: (1) temporal differences, (2) sensor differences,

(3) different Quality Levels and accuracy standards, or (4) differences between topographic and bathymetric surfaces along the ever-changing tidal zone, for example.

There are many questions to be answered prior to determining whether or not it is actually desirable to manipulate elevation datasets either horizontally or vertically to make them seamless such as which dataset to hold as control, how far into a dataset do you make adjustments, what if the adjustment changes the accuracy of the dataset, etc.

Table 58 depicts the amount of vertical manipulation that is acceptable to respondents in order to achieve seamlessness within nearshore bathymetric datasets. The greatest number of respondents (50%) reported that the amount of acceptable vertical manipulation to achieve spatial seamlessness is "Up to the required TVU at the 95% confidence level." However, the next most frequently reported response is "I don't know" (25%), indicating that many respondents did not feel comfortable answering this question.

Table 58. Acceptable vertical manipulation to achieve seamlessness within nearshore bathymetric datasets

Acceptable Vertical Manipulation to Achieve Seamlessness within Nearshore Bathymetric Datasets	Total MCAs	Percent of MCAs
Up to the required TVU at the 95% confidence level	330	50%
Up to double the required TVU at the 95% confidence level	62	9%
Up to triple the required TVU at the 95% confidence level	15	2%
Whatever it takes to achieve seamlessness, including changes to the older, previously accepted dataset if it is proven to be less accurate than the newer	83	13%
I don't know	163	25%
None	2	0%
Other	4	1%
No response	3	0%
Total	662	100%

5.3.4.7. 3D Data Products

Respondents were asked about the importance of the following 3D data products to accomplishing their MCAs. The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 59 depicts the data products ranked by the number of MCAs for which that data product is "Required" for Nearshore Bathymetry.

To account for responses other than "Required," the last column in Table 59 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

DEMs are the most frequently required, followed by DTMs, ground control/ground truthing, DTMs, DSMs, and raw point cloud data. Using the weighted average score would change the order of the responses slightly and would place classified point cloud data in the top five instead of raw point cloud data.

Table 59. Required nearshore bathymetric data products ranked by the number of MCAs for which that data product is "Required"

Required Nearshore Bathymetric Data Products	Total MCAs	Percent of MCAs	Weighted Average
DEM	519	78%	703
Ground Control/Ground Truthing	264	40%	531
DTM	247	37%	514
DSM	197	30%	482
Raw Point Cloud	146	22%	361
Classified Point Cloud	132	20%	414
National Vertical Transformation Tool (V-Datum)	114	17%	347
Tide Predictions	106	16%	293
BAG	63	10%	265
Intensity Imagery/Sidescan Imagery	53	8%	311
Edited/Cube XYZ	27	4%	197
TCARI	25	4%	197
Full Waveform	18	3%	161
Other	7	1%	11

5.3.4.8. Level of Integration with Other Data Products

Respondents were asked about the importance of integrating 3D nearshore bathymetric data with other datasets to accomplishing their MCAs. Examples of data integration would be data that align either spatially and/or temporally or attribute codes that are logically consistent.

The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 60 depicts the data products ranked by the number of MCAs for which integration with that data product is "Required" for Nearshore Bathymetry.

To account for responses other than "Required," the last column in Table 60 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

Integration of 3D nearshore bathymetric data with hydrographic survey data is the most frequently required, followed by coastal structures, aerial and/or satellite imagery, shorelines, and wetlands.

Using the weighted average score would change the order of the responses slightly, placing coastal structures first and replacing wetlands with estuaries in the list of the top five.

Table 60. Datasets required to be integrated with Nearshore Bathymetry ranked by the number of MCAs for which integration is "Required"

Datasets Required to be Integrated with Nearshore Bathymetry	Total MCAs	Percent of MCAs	Weighted Average
Hydrographic Survey Data	280	42%	552
Coastal Structures	263	40%	556
Aerial and/or Satellite Imagery	259	39%	548
Shorelines	240	36%	555
Wetlands	214	32%	511
Inland Surface Water Features	205	31%	483
Estuaries	203	31%	514
Fixed Obstructions	138	21%	353
Overhead Structures	137	21%	384
Tide Heights, Wave Heights	103	16%	346
Land Use/Land Cover	103	16%	419
Submerged Features	102	15%	401
Nautical and/or Navigation Charts	87	13%	333
Floating Observation and Navigation Systems	80	12%	336
Bottom Type	79	12%	371
Routes	72	11%	263
Boundaries	66	10%	283
Habitat Distribution and Classification	59	9%	308
Cultural Resources	56	8%	266
Acoustic Imagery of the Seafloor	53	8%	305
Geologic and/or Seismic Data	51	8%	229
Sub Bottom Characteristics	49	7%	258
Currents	48	7%	291
Bottom Texture	45	7%	265
Lease Areas	45	7%	208
Landmark Features	39	6%	294
Offshore Cadastral	26	4%	193
Water Column Properties - Physical	25	4%	186
Sea Ice Conditions	25	4%	111
Water Column Properties - Biological	24	4%	173
Water Column Properties - Chemical	21	3%	168
Underwater Videography	11	2%	115

Datasets Required to be Integrated with Nearshore Bathymetry	Total MCAs	Percent of MCAs	Weighted Average
Other	1	0%	2

5.3.4.9. Derivative Products

Respondents were asked what derivative products they need to be able to generate from 3D nearshore bathymetric data to accomplish their MCAs. Respondents were able to select multiple data derivatives as being needed.

Table 61 depicts the data derivatives ranked by the number of MCAs for which that product is needed for Nearshore Bathymetry. Contours are the most frequently required, followed by hillshades, TINs, slope maps, and cross sections.

Table 61. Data derivatives needed from Nearshore Bathymetry ranked by the number of MCAs for which that product is needed

Data Derivatives Needed from Nearshore Bathymetry	Total MCAs	Percent of MCAs
Contours	230	35%
Hillshades	153	23%
TIN	152	23%
Slope Maps	145	22%
Cross Sections	132	20%
Rugosity/Surface Roughness	98	15%
Aspect Maps	86	13%
Hydrologic Units	59	9%
Curvature Maps	58	9%
Hydrologic Networks	58	9%
Hydrologic Flow Direction Grids	55	8%
Height-Above-Ground-Maps	53	8%
Hydrologic Flow Accumulation Grids	41	6%
Building Footprints	38	6%
Viewshed Maps	34	5%
Breaklines for Road Edge-of-Pavement	20	3%

5.3.4.10. National Sources of 3D Nearshore Bathymetric Data

Respondents were asked to indicate what national sources of nearshore bathymetric data are currently being used to address the elevation information needs of their MCA. Specifically, respondents were asked about their use of NOAA sources, including the Digital Coast, NCEI, and NOAA nautical charts, the USACE inland electronic navigation charts, BOEM's Marine Minerals Program GIS (MMPGIS), state repositories, and other data sources.

Table 62 provides a summary of the current use of national repositories of 3D Nearshore Bathymetry ranked by the number of MCAs for which that data source is used. NOAA navigation charts and the Digital Coast are most frequently used as a source of nearshore bathymetric data.

When "Other" data sources are used, 55 percent of the time it is locally developed and/or maintained elevation data. These locally collected and/or maintained data are either of higher resolution than the national datasets, having been collected for specific uses or sites, or improved or customized to serve the business needs of the MCA.

Table 62. Sources of nearshore bathymetric data ranked by the number of MCAs for which data are acquired there

Sources of Nearshore Bathymetric Data	Total MCAs	Percent of MCAs
NOAA Nautical Charts	237	19%
NOAA Digital Coast	215	17%
NOAA NCEI	132	10%
Other	78	6%
State Repositories	66	5%
USACE Inland Electronic Navigation Charts	57	4%
BOEM MMPGIS	24	2%

5.3.5. Offshore Bathymetry Requirements

This section summarizes the requirements for 3D elevation data for Offshore Bathymetry provided by the study respondents.

5.3.5.1. Acceptable Horizontal and Vertical Error

Respondents were asked about the amount of horizontal and vertical error that is acceptable in the 3D offshore bathymetric data they use or need. Specifically, they were asked about the acceptable amount of THU or TVU at the 95% confidence level.

Table 63 depicts the amount of horizontal error that is acceptable to respondents for Offshore Bathymetry. The greatest number of respondents (26%) reported a requirement for horizontal accuracy of “Up to 5 meters.” This level of horizontal accuracy is equivalent to that achievable by IHO Order 1 offshore bathymetric data. However, an equal number of respondents said, “I don’t know.”

Table 63. Horizontal accuracy requirements at the 95% confidence level for Offshore Bathymetry

Horizontal Accuracy Requirements at the 95% Confidence Level for Offshore Bathymetry	Total MCAs	Percent of MCAs
Less than 50 cm	18	5%
Up to 1 m	32	9%
Up to 2 m	64	17%
Up to 5 m	96	26%
Up to 10 m	5	1%
Up to 20 m	25	7%
Greater than 20 m	5	1%
The best horizontal accuracy achievable for the vertical accuracy I need	26	7%
I don’t know	97	26%
Other	1	0%
No response	1	0%
Total	370	100%

Table 64 depicts the amount of vertical error that is acceptable to respondents for Offshore Bathymetry. The greatest number of respondents (54%) reported a requirement for vertical accuracy of “less than 1 meter.” This level of vertical accuracy is equivalent to that achievable by IHO Order 1 offshore bathymetric data.

Table 64. Vertical accuracy requirements at the 95% confidence level for Offshore Bathymetry

Vertical Accuracy Requirements at the 95% Confidence Level for Offshore Bathymetry	Total MCAs	Percent of MCAs
Less than 1 m	201	54%
Up to 2 m	40	11%
Up to 5 m	8	2%
Up to 10 m	4	1%
Up to 20 m	1	0%
Greater than 20 m	1	0%
I don't know	101	27%
Other	14	4%
Total	370	100%

5.3.5.2. *Quality Level*

Respondents were asked what 3D bathymetric data Quality Level they require for the Offshore Bathymetry portion of their MCA.

Table 65 and Figure 26 depict the Quality Level requirements for Offshore Bathymetry. The greatest number of respondents (20%) reported a requirement for Order 1a data. However, an equal number of respondents said, "I don't know," while another 19% reported a requirement for Special Order data. In total, 38% reported a requirement for Order 1, 1a, or 1b data.

Table 65. Quality Level requirements for Offshore Bathymetry

Quality Level Requirements for Offshore Bathymetry	Total MCAs	Percent of MCAs
Special Order	72	19%
Order 1a	74	20%
Order 1b	32	9%
Order 1	32	9%
Order 2	35	9%
Order 3	4	1%
Coarser data meet needs	1	0%
Don't know	75	20%
Cross sections meet needs	36	10%
Other/Mixed	9	3%
No response	0	0%
Total	370	100%

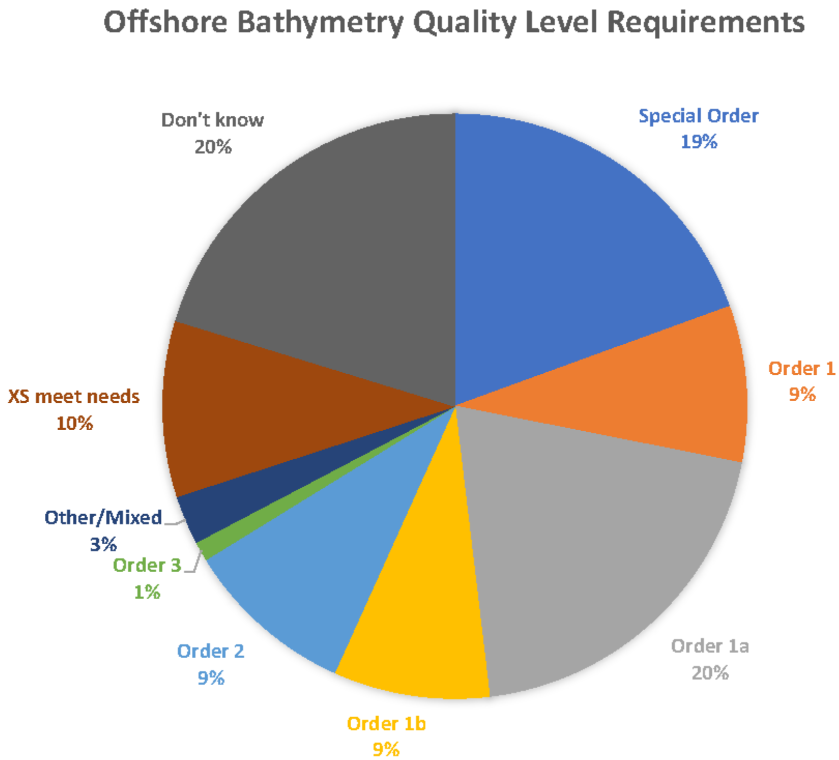


Figure 26. Offshore Bathymetry Quality Level requirements

5.3.5.3. Update Frequency

Respondents were asked how frequently the 3D bathymetric data need to be updated to satisfy the requirements of the Offshore Bathymetry portion of their MCA.

Table 66 and Figure 27 depict the update frequency requirements for Offshore Bathymetry. The greatest number of respondents (27%) reported a requirement for offshore bathymetric data to be updated every 4-5 years. The next most frequently reported requirement is for offshore bathymetric data to be updated every 2-3 years (24%), with an equal number (24%) reporting a requirement for offshore bathymetric data to be updated every 6-10 years.

Table 66. Update frequency requirements for Offshore Bathymetry

Update Frequency Requirements for Offshore Bathymetry	Total MCAs	Percent of MCAs
Annually	8	2%
2-3 years	90	24%
4-5 years	99	27%
6-10 years	90	24%
>10 years	16	4%
Event driven only	18	5%
Don't know	42	12%
Other/Mixed	7	2%

Update Frequency Requirements for Offshore Bathymetry	Total MCAs	Percent of MCAs
No response	0	0%
Total	370	100%

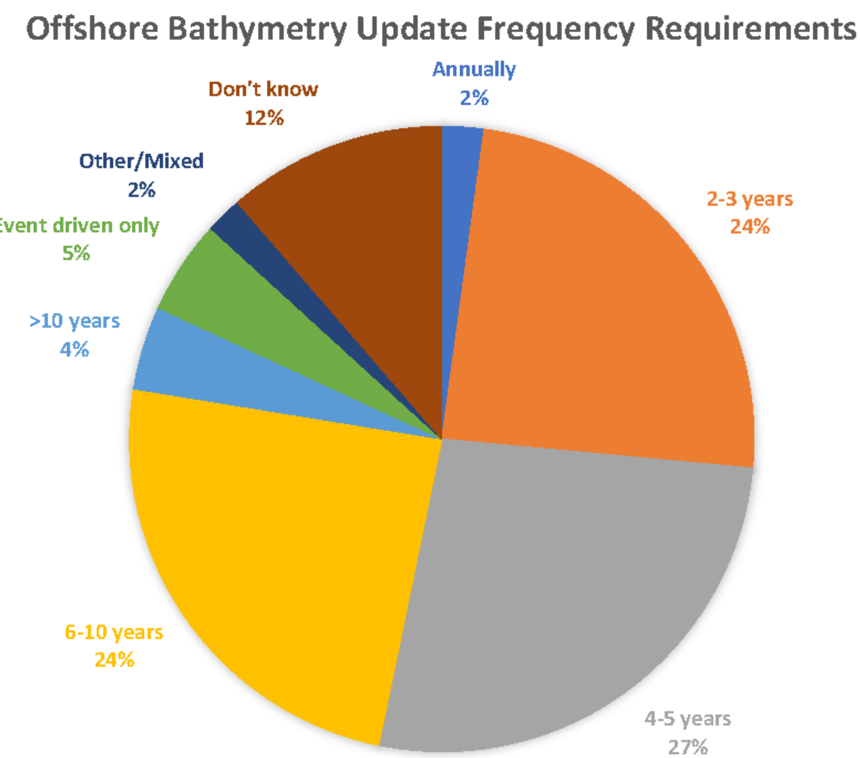


Figure 27. Offshore Bathymetry Update Frequency Requirements

5.3.5.4. Tide Correction

Respondents were asked if there is a requirement for the 3D offshore bathymetric data to be tide corrected to meet the needs of the Offshore Bathymetry portion of their MCA.

Table 67 depicts the requirements for tide correction for 3D offshore bathymetric data. Of the 159 applicable responses, the greatest number with a requirement for tide correction reported a requirement for tide correction using MLLW. The next most frequently reported response is that tide correction is not required. And a significant number said they do not know what their requirement for tide correction is.

Table 67. Tide correction requirements for Offshore Bathymetry

Tide Correction requirements for Offshore Bathymetry	Total MCAs	Percent of MCAs
No requirement for tide correction	30	19%
Tide correction using MHW	25	16%
Tide correction using MSL	13	8%

Tide Correction requirements for Offshore Bathymetry	Total MCAs	Percent of MCAs
Tide correction using MLLW	39	25%
NAVD88	4	3%
Other	11	7%
I don't know	25	16%
No response	12	8%
Total	159	100%

5.3.5.5. Seamlessness within Offshore Bathymetry

Respondents were asked about the importance of seamless integration within the 3D offshore bathymetric data to accomplishing their MCAs. Examples of data integration would be data collected at the same time (temporal integration) or data that spatially align between adjacent geographic areas (spatial integration). The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Note that questions were also asked about the importance of seamlessness between topography, bathymetry, and topobathymetry (i.e., between Nearshore Bathymetry and Offshore Bathymetry). Those results are presented in Tables 75 – 77.

Spatial Integration

Seamless spatial integration refers to the integration of different datasets so that users cannot see seamlines between the two datasets (e.g., no obvious cliffs or voids where datasets join).

Table 68 depicts the importance of spatial seamlessness of DEMs and point clouds within Offshore Bathymetry. The greatest number of respondents reported that spatial seamlessness for DEMs is "Highly desirable" (39%) The next most frequently reported response for DEMs is "Required" (30%). The greatest number of respondents reported that spatial seamlessness for point clouds is "Highly desirable" (41%). The next most frequently reported response for point clouds is "Required" (20%).

Table 68. Requirements for spatial seamlessness within offshore bathymetric datasets

Requirements for Spatial Seamlessness within Offshore Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know/No Response
DEM Seamlessness	110	30%	143	39%	53	14%	11	3%	53	14%
Point Cloud Seamlessness	74	20%	151	41%	68	18%	24	6%	53	14%

Temporal Integration

Seamless temporal integration refers to the integration of multiple 3D datasets acquired at different times to reduce discontinuities between datasets acquired on different dates, and so that a user cannot see the differences. Temporal changes most commonly occur when the goal is to acquire 3D data under specific conditions, such as leaf-off conditions; early snowfall in the fall may cause data acquisition to be halted until the following spring, or leaf-on conditions in the spring may cause data acquisition to be halted until the following fall when leaf-off conditions return. Changes in water surface levels may be apparent due to the different time periods of collection.

Exceptions are routinely made when data acquisition flights are interrupted by unavoidable events such as natural disasters, e.g., wildfires, hurricanes, tornadoes, earthquakes or floods that change the 3D landscape. Other exceptions are with tidal waters that continuously change coastal shorelines. In the case of tidal variations, the temporal integration of datasets acquired even just an hour apart may not be seamless. Other temporal variations may also be unavoidable.

Table 69 depicts the importance of data collection under similar environmental conditions (e.g., similar low streamflow conditions, turbidity, or other weather conditions, etc.) and the importance of data collection in the same acquisition season (e.g., Fall 2020), regardless of environmental conditions, within Offshore Bathymetry. The greatest number of respondents (41%) reported that temporal seamlessness for environmental conditions is "Highly desirable." The next most frequently reported response for environmental conditions is "Nice to have" (25%). The greatest number of respondents (41%) reported that temporal seamlessness for seasonal conditions is "Nice to have." The next most frequently reported response for seasonal conditions is "Highly desirable" (25%).

Table 69. Requirements for temporal seamlessness within offshore bathymetric datasets

Requirements for Temporal Seamlessness within Offshore Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know/No Response
Environmental Seamlessness	41	11%	150	41%	93	25%	34	9%	52	14%
Seasonal Seamlessness	31	8%	93	25%	151	41%	43	12%	52	14%

Acceptable Vertical Manipulation

When merging or joining one elevation dataset to another, there is normally a visible seamline between disparate elevation datasets because of: (1) temporal differences, (2) sensor differences, (3) different Quality Levels and accuracy standards, or (4) differences between topographic and bathymetric surfaces along the ever-changing tidal zone, for example.

There are many questions to be answered prior to determining whether or not it is actually desirable to manipulate elevation datasets either horizontally or vertically to make them seamless such as which dataset to hold as control, how far into a dataset do you make adjustments, what if the adjustment changes the accuracy of the dataset, etc.

Table 70 depicts the amount of vertical manipulation that is acceptable to respondents in order to achieve seamlessness within offshore bathymetric datasets. The greatest number of respondents (45%) reported that the amount of acceptable vertical manipulation to achieve spatial seamlessness is "Up to the required TVU at the 95% confidence level." However, the next most frequently reported response is "I don't know" (34%), indicating that many respondents did not feel comfortable answering this question.

Table 70. Acceptable vertical manipulation to achieve seamlessness within offshore bathymetric datasets

Acceptable Vertical Manipulation to Achieve Seamlessness within Offshore Bathymetric Datasets	Total MCAs	Percent of MCAs
Up to the required TVU at the 95% confidence level	167	45%
Up to double the required TVU at the 95% confidence level	23	6%
Up to triple the required TVU at the 95% confidence level	7	2%
Whatever it takes to achieve seamlessness, including changes to the older, previously accepted dataset if it is proven to be less accurate than the newer	33	9%
I don't know	126	34%
None	2	1%
Other	2	1%
No response	10	3%
Total	370	100%

5.3.5.6. 3D Data Products

Respondents were asked about the importance of the following 3D data products to accomplishing their MCAs. The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 71 depicts the data products ranked by the number of MCAs for which that data product is "Required" for Offshore Bathymetry.

To account for responses other than "Required," the last column in Table 71 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

DEMs are the most frequently required, followed by DSMs, ground control/ground truthing, DTMs, and raw point cloud data. Using the weighted average score would change the order of the responses slightly but would not change the list of the top five.

Table 71. Required offshore bathymetric data products ranked by the number of MCAs for which that data product is "Required"

Required Offshore Bathymetric Data Products	Total MCAs	Percent of MCAs	Weighted Average
DEM	258	70%	355
DSM	128	35%	268
Ground Control/Ground Truthing	122	33%	266
DTM	109	29%	251
Raw Point Cloud	86	23%	198
Intensity Imagery	47	13%	197
Tide Predictions	44	12%	155
V-Datum	39	11%	153
BAG	30	8%	165
TCARI	27	7%	129
Edited/Cube XYZ	26	7%	118
Full Waveform	16	4%	98
Other	2	1%	3

5.3.5.7. Level of Integration with Other Data Products

Respondents were asked about the importance of integrating 3D offshore bathymetric data with other datasets to accomplishing their MCAs. Examples of data integration would be data that align either spatially and/or temporally or attribute codes that are logically consistent.

The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Table 72 depicts the data products ranked by the number of MCAs for which integration with that data product is "Required" for Offshore Bathymetry.

To account for responses other than "Required," the last column in Table 72 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don't know = 0.

Integration of 3D offshore bathymetric data with hydrographic survey data is the most frequently required, followed by nautical and/or navigation charts, submerged features, aerial and/or satellite imagery, and fixed obstructions. Using the weighted average score would change the order of the slightly, replacing bottom type for fixed obstructions in the list of the top five.

Table 72. Datasets required to be integrated with Offshore Bathymetry ranked by the number of MCAs for which integration is "Required"

Datasets Required to be Integrated with Offshore Bathymetry	Total MCAs	Percent of MCAs	Weighted Average
Hydrographic Survey Data	176	48%	311
Nautical and/or Navigation Charts	130	35%	272
Submerged Features	118	32%	265
Aerial and/or Satellite Imagery	116	31%	261
Fixed Obstructions	113	31%	235
Bottom Type	89	24%	247
Wetlands	87	24%	223
Floating Observation and Navigation Systems	82	22%	224
Acoustic Imagery	78	21%	227
Estuaries	78	21%	219
Tide Heights, Wave Heights	69	19%	204
Boundaries	63	17%	199
Bottom Texture	60	16%	200
Habitat Distribution and Classification	51	14%	192
Subbottom Characteristics	45	12%	182
Routes	44	12%	153
Currents	43	12%	187
Lease Areas	40	11%	153
Geologic and/or Seismic Data	36	10%	166
Offshore Cadastral	28	8%	126
Land Use/Land Cover	27	7%	162
Water Column Properties - Biological	23	6%	136
Water Column Properties - Physical	22	6%	150
Sea Ice Conditions	18	5%	77
Water Column Properties - Chemical	17	5%	133
Underwater Videography	15	4%	93
Other	1	0%	3

5.3.5.8. Derivative Products

Respondents were asked what derivative products they need to be able to generate from 3D offshore bathymetric data to accomplish their MCAs. Respondents were able to select multiple data derivatives as being needed.

Table 73 depicts the data derivatives ranked by the number of MCAs for which that product is needed for Offshore Bathymetry. Contours are the most frequently required, followed by TINs, hillshades, slope maps, and cross sections.

Table 73. Data derivatives needed from Offshore Bathymetry ranked by the number of MCAs for which that product is needed

Data Derivatives Needed from Offshore Bathymetry	Total MCAs	Percent of MCAs
Contours	113	31%
TIN	74	20%
Hillshades	73	20%
Slope Maps	71	19%
Cross Sections	57	15%
Rugosity	51	14%
Aspect Maps	47	13%
Curvature Maps	35	9%
Height-Above-Ground-Maps	26	7%
Hydrologic Flow Direction Grids	20	5%
Viewshed Maps	16	4%
Hydrologic Units	15	4%
Hydrologic Networks	14	4%
Hydrologic Flow Accumulation Grids	13	4%
Building Footprints	9	2%
Breaklines for Road Edge-of-Pavement	5	1%

5.3.5.9. National Sources of 3D Offshore Bathymetric Data

Respondents were asked to indicate what national sources of offshore bathymetric data are currently being used to address the elevation information needs of their MCA. Specifically, respondents were asked about their use of NOAA sources, including the Digital Coast, NCEI, and NOAA nautical charts, the USACE inland electronic navigation charts, BOEM's MMPGIS, and other data sources.

Table 74 provides a summary of the current use of national repositories of 3D Offshore Bathymetry ranked by the number of MCAs for which that data source is used. NOAA navigation charts and the Digital Coast are most frequently used as a source of nearshore bathymetric data.

When "Other" data sources are used, 18 percent of the time it is developed and/or maintained by the state and 39 percent of the time it is locally developed and/or maintained elevation data. These data collected and/or maintained by states are either of higher resolution than the national datasets, having been collected for specific uses or sites, or improved or customized to serve the business needs of the MCA.

Table 74. Sources of offshore bathymetric data ranked by the number of MCAs for which data are acquired there

Sources of Offshore Bathymetric Data	Total MCAs	Percent of MCAs
NOAA Nautical Charts	126	34%
NOAA NCEI	96	26%
NOAA Digital Coast	92	25%
USACE Electronic Navigation Charts	39	11%
Other	28	8%

5.3.6. Requirements Across All Geographies

Respondents were asked a few final questions that apply to all geography types, including about requirements for seamlessness across geographies, data access and archiving, and whether they require assistance or training in acquiring or using elevation data.

5.3.6.1. Seamlessness between Topographic, Bathymetric, and/or Topobathymetric Data

Respondents were asked about the importance of seamless integration between topographic, bathymetric, and/or topobathymetric data across the entire area of interest of their MCAs. Examples of data integration would be data collected at the same time (temporal integration) or data that spatially align between adjacent geographic areas (spatial integration). The options provided for answering this question in the online questionnaire were "Required," "Highly desirable," "Nice to have," and "Not required."

Note that questions were also asked about seamlessness within geography types (e.g., within Inland Topography) and between Inland Topography and Inland Bathymetry. Those results are presented in Tables 25 – 27 (for Inland Topography), Tables 38 – 40 (for Inland Bathymetry), Tables 56 – 58 (for Nearshore Bathymetry), and Tables 68 – 70 (for Offshore Bathymetry).

Spatial Integration

Table 75 depicts the importance of spatial seamlessness of DEMs and point clouds between topographic, bathymetric, and/or topobathymetric data. The greatest number of respondents reported that spatial seamlessness between topography and bathymetry for DEMs is "Required" (42%) The next most frequently reported response for DEMs is "Highly desirable" (36%). The greatest number of respondents reported that spatial seamlessness between topographic, bathymetric, and/or topobathymetric point clouds is "Highly desirable" (48%). The next most frequently reported response for point clouds is "Nice to have" (23%).

Table 75. Requirements for spatial seamlessness between topographic, topobathymetric, and/or bathymetric datasets

Requirements for Spatial Seamlessness between Topographic, Topobathymetric, and/or Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know/No Response
DEM Seamlessness	275	42%	241	36%	84	13%	29	4%	33	5%
Point Cloud Seamlessness	111	17%	318	48%	153	23%	47	7%	33	5%

Temporal Integration

Table 76 depicts the importance of data collection under similar environmental conditions (e.g., similar low streamflow conditions, turbidity, or other weather conditions, etc.) and the importance of data collection in the same acquisition season (e.g., Fall 2020), regardless of environmental conditions, between topographic, bathymetric, and/or topobathymetric data.

The greatest number of respondents (47%) reported that temporal seamlessness between topographic, bathymetric, and/or topobathymetric data for environmental conditions is "Highly desirable." The next most frequently reported response for environmental conditions is "Nice to have" (23%). The greatest number of respondents (38%) reported that temporal seamlessness between topographic, bathymetric, and/or topobathymetric data for seasonal conditions is "Nice to have." The next most frequently reported response for seasonal conditions is "Highly desirable" (34%).

Table 76. Requirements for temporal seamlessness between topographic, topobathymetric, and/or bathymetric datasets

Requirements for Temporal Seamlessness between Topographic, Topobathymetric, and/or Bathymetric Datasets	Required	Percent Required	Highly Desirable	Percent Highly Desirable	Nice to Have	Percent Nice to Have	Not Required	Percent Not Required	I Don't Know/No Response	Percent I Don't Know
Environmental Seamlessness	122	18%	308	47%	152	23%	47	7%	33	5%
Seasonal Seamlessness	81	12%	227	34%	252	38%	69	10%	33	5%

Acceptable Vertical Manipulation

Table 77 depicts the amount of vertical manipulation that is acceptable to respondents in order to achieve seamlessness between topographic, bathymetric, and/or topobathymetric datasets. The greatest number of respondents (54%) reported that the amount of acceptable vertical manipulation to achieve spatial seamlessness is "Up to the required TVU at the 95% confidence level." However, the next most frequently reported response is "I don't know" (23%), indicating that many respondents did not feel comfortable answering this question.

Table 77. Acceptable vertical manipulation to achieve seamlessness between topographic, bathymetric, and topobathymetric datasets

Acceptable Vertical Manipulation to Achieve Seamlessness between Topographic, Bathymetric, and/or Topobathymetric Datasets	Total MCAs	Percent of MCAs
Up to the required TVU at the 95% confidence level	360	54%
Up to double the required TVU at the 95% confidence level	48	7%
Up to triple the required TVU at the 95% confidence level	14	2%
Whatever it takes to achieve seamlessness, including changes to the older, previously accepted dataset if it is proven to be less accurate than the newer	72	11%
I don't know	153	23%
None	1	0%
Other	4	1%
No response	10	2%
Total	662	100%

5.3.6.2. Ranking of Requirements

Respondents were asked to rank the importance of three aspects of their 3D elevation requirements: geographic coverage, vertical accuracy, and update frequency.

Table 78 and Figure 28 depict the ranked importance of geographic coverage, vertical accuracy, and update frequency. The greatest number of respondents reported that update frequency is most important (74%), followed by vertical accuracy (15%), and finally geographic coverage (11%).

Table 78. Ranked importance of update frequency, vertical accuracy, and geographic coverage

Ranked Value	Total MCAs Update Frequency	Percent of MCAs Update Frequency	Total MCAs Geographic Coverage	Percent of MCAs Geographic Coverage	Total MCAs Vertical Accuracy	Percent of MCAs Vertical Accuracy
1	999	74%	131	10%	158	12%
2	199	15%	313	23%	776	57%
3	90	7%	844	62%	354	26%

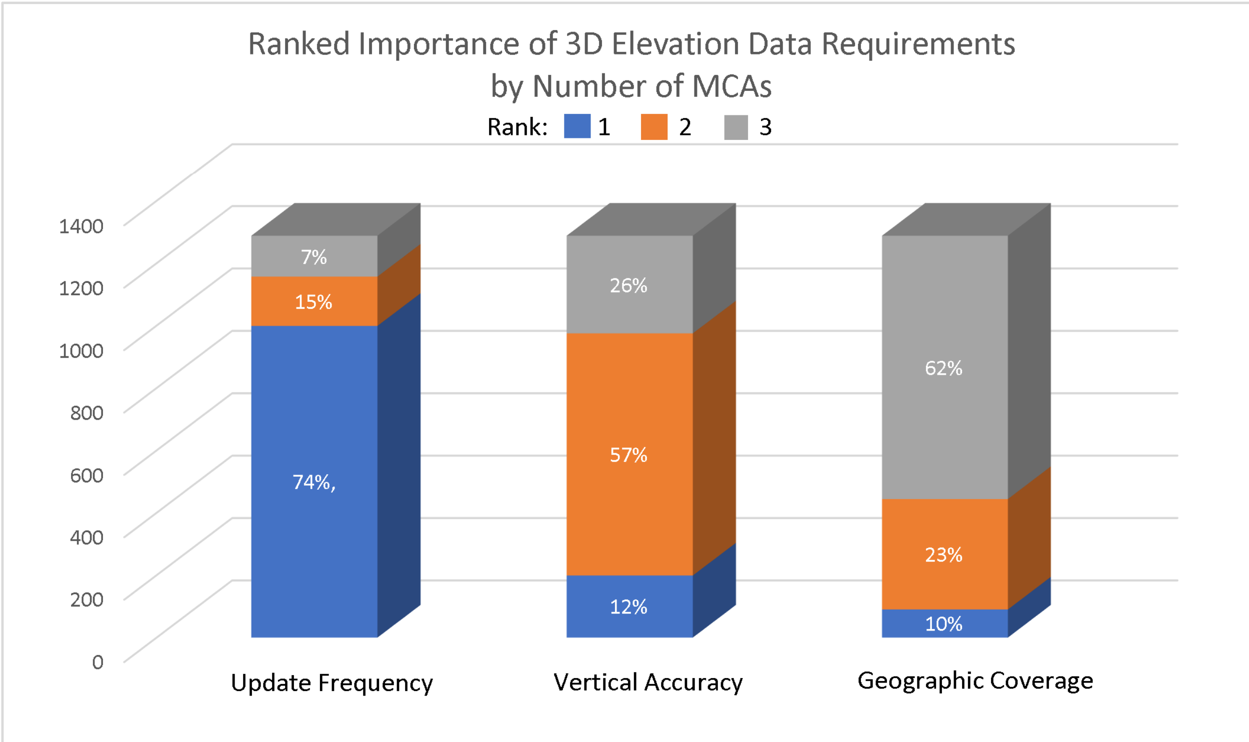


Figure 28. Ranked importance of update frequency, vertical accuracy, and geographic coverage

5.3.6.3. Data Archiving and Access

Respondents were asked about their requirements for access to publicly available 3D elevation data, where they archive elevation data if they acquire their own data, and what data or file formats are preferred for 3D elevation data.

Table 79 depicts the importance to respondents of having data archived/stored in such a way that it is freely available for the public to find, get, and use. The greatest number of respondents (41%) reported that data access is "Required." The next most frequently reported response is "Highly desirable" (34%).

Table 79. Requirements for access to 3D elevation data for all geographies

Requirements for Access to 3D Elevation Data	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
Required	529	42%	355	43%	287	43%	164	44%	557	41%
Highly desirable	432	34%	277	33%	219	33%	123	33%	456	34%
Nice to have	182	14%	116	14%	88	13%	45	12%	203	15%
Not required	0	0%	0	0%	0	0%	0	0%	0	0%
I don't know	110	9%	74	9%	58	9%	34	9%	117	9%
No response	19	1%	9	1%	10	2%	4	1%	19	1%
Total	1,272	100%	831	100%	662	100%	370	100%	1,352	100%

Respondents were asked whether they archive/store elevation data that they acquire or purchase in such a way that it is freely available for the public to find, get, and use. Table 80 depicts the data storage/archive locations ranked by the number of MCAs for which that location is listed. Internal storage locations are the most frequently used (71%), followed agency/organization enterprise geospatial systems (54%). Unfortunately, submittal to resources that are most readily accessible to the public (state and federal repositories) is considerably underrepresented in these responses, meaning a large volume of data may be undiscoverable by the public even if its acquisition was funded with taxpayer dollars.

Table 80. 3D Elevation Data storage/archive locations ranked by the number of MCAs for which that location is listed

3D Elevation Data Storage/Archive Location	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
Agency/Organization Internal Resources	903	71%	609	73%	486	73%	276	75%	961	71%
Agency Enterprise Geospatial System	702	55%	461	55%	351	53%	197	53%	734	54%
Submit to State Data Repository	435	34%	269	32%	201	30%	119	32%	443	33%
Submit to NOAA's NCEI	122	10%	79	10%	67	10%	38	10%	124	9%
Submit to USGS	66	5%	58	7%	65	10%	45	12%	75	6%
Submit to MarineCadastre	47	4%	41	5%	53	8%	40	11%	58	4%
Submit to Digital Coast	44	3%	23	3%	22	3%	13	4%	47	3%
Submit to Third Party Cloud Provider	11	1%	10	1%	12	2%	12	3%	14	1%

Respondents were asked what their preferred data format(s) are for 3D elevation data. Respondents were able to select multiple data formats as being preferred. Table 81 depicts the data formats ranked by the number of MCAs for which that file format is preferred. Overall preferences are for data to be provided as raster GeoTIFF files, followed by vector file GDBs, mass point LAS files, gridded GeoTIFF files, and vector Shapefiles.

Table 81. 3D elevation data formats ranked by the number of MCAs for which that file format is preferred

Preferred Data Formats	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
Raster GeoTIFF	1171	92%	767	92%	607	92%	338	91%	1,237	91%
Vector File GDB	1158	91%	751	90%	593	90%	332	90%	1,223	90%
Mass Points LAS	1067	84%	715	86%	541	82%	306	83%	1,121	83%
Gridded GeoTIFF	1042	82%	708	85%	562	85%	316	85%	1,104	82%
Vector Shapefile	1010	79%	680	82%	532	80%	304	82%	1,073	79%

Preferred Data Formats	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs
Other TIN	777	61%	520	63%	398	60%	233	63%	818	61%
Raster MrSID	686	54%	456	55%	352	53%	187	51%	718	53%
Gridded ArcGrid	685	54%	452	54%	334	50%	193	52%	711	53%
Raster TIFF	597	47%	390	47%	299	45%	169	46%	632	47%
Vector OGC	461	36%	298	36%	214	32%	113	31%	480	36%
Gridded IMG	440	35%	295	36%	222	34%	118	32%	454	34%
Gridded ASCII	384	30%	299	36%	230	35%	125	34%	422	31%
Gridded DTED	368	29%	231	28%	184	28%	102	28%	390	29%
MassPoints ASCII	343	27%	243	29%	199	30%	115	31%	380	28%
Raster GeoPDF	282	22%	210	25%	170	26%	99	27%	317	23%
Gridded BAG	249	20%	205	25%	182	27%	122	33%	290	21%
Raster PDF	242	19%	167	20%	140	21%	80	22%	268	20%
Raster RNC	156	12%	122	15%	123	19%	82	22%	191	14%
Vector ENC	142	11%	106	13%	110	17%	76	21%	176	13%
Gridded NetCDF	123	10%	82	10%	75	11%	51	14%	134	10%
Gridded GridFloat	129	10%	81	10%	57	9%	34	9%	134	10%
Other	13	1%	8	1%	7	1%	4	1%	14	1%

Respondents were asked about the importance of various 3D elevation data or web service access methods. Table 82 depicts the 3D elevation data or web service access methods ranked by the number of MCAs for which that method was listed as “Required” for all geographies.

To account for responses other than “Required,” the last column in Table 82 shows a weighted average of the responses to each question. The weighting was done as follows: Required = 5, Highly desirable = 3, Nice to have = 1, Not required/No response/I don’t know = 0.

The greatest number of respondents reported that web services to download data are needed (6%), followed by webservices to discover data (56%), web services to dynamically use GIS services (19%), web services to visualize data (13%), mashups (9%) and web services to create customized products (8%). Using the weighted average score would change the order of the responses slightly but only the order of the last two. These responses indicate that finding and downloading data are the most important web services to elevation data users.

Table 82. 3D elevation data or web service access methods ranked by the number of MCAs for which that method is required

3D Elevation Data or Web Service Access Methods	Inland Topo MCAs	Pct. Inland Topo	Inland Bathy MCAs	Pct. Inland Bathy	Nearshore Bathy MCAs	Pct. Nearshore Bathy	Offshore Bathy MCAs	Pct. Offshore Bathy	Total MCAs	Pct. of MCAs	Weighted Average
Web services to download data	775	61%	519	62%	422	64%	235	64%	824	61%	3.93
Web services to discover data	714	56%	477	57%	406	61%	229	62%	759	56%	3.81
Web services to dynamically use GIS services	236	19%	143	17%	121	18%	72	19%	251	19%	2.78
Web services to visualize data	151	12%	106	13%	105	16%	61	16%	174	13%	2.27
Web services to combine visualizations from multiple services (i.e., mash-ups)	112	9%	72	9%	73	11%	44	12%	123	9%	1.85
Web services to create customized products	96	8%	69	8%	53	8%	37	10%	104	8%	2.17

5.4. Benefits

Respondents were asked questions about the benefits to their program that are currently being realized from the currently available 3D elevation data as well as the future annual benefits their program would gain from having their expressed requirements for 3D elevation data met. These questions were asked to get a sense of the current value of available elevation data as well as to solicit future annual dollar benefits that can be used in B/C and ROI Analyses.

5.4.1. Current Benefits

Respondents were asked to provide a qualitative estimate of the benefits, relative to their program, they are currently realizing from the currently available 3D elevation data.

The question was asked about the following categories.

- Operational Benefits, which include time savings, cost savings or cost reductions (e.g., savings on purchases), increased revenues to the organization, and mission-driven performance improvements.
- Customer Service Benefits, which include value added to products or services, improved response or timeliness, and improved customer experience.
- Societal Benefits, which include education or outreach; environmental benefits; and public safety, including life and property.

The options provided for answering this question in the online questionnaire were "Major," "Moderate," "Minor," "None," and "Don't know."

Table 83 depicts the number MCAs for which "Major" current benefits were reported for each benefit category and geography type.

Table 83. Intangible current benefits by Geography Type

Geography Type	Major Intangible Operational Benefits	Major Intangible Customer Service Benefits	Major Education & Outreach Benefits	Major Environ-mental Benefits	Major Public Safety and Other Benefits
Inland Topography	1,023	836	388	609	653
Inland Bathymetry	321	263	77	139	131
Nearshore Bathymetry	209	152	103	140	141
Offshore Bathymetry	138	108	66	89	81
Total	1,691	1,359	634	977	1,006

5.5.1. Future Annual Benefits

Respondents were asked to provide both a qualitative and a quantitative estimate of the future benefits their program would gain from having their requirements for 3D elevation data met.

For the following categories, respondents were asked to estimate both qualitative and quantitative (dollar) future annual benefits:

- Operational Benefits, which include time savings, cost savings or cost reductions (e.g., savings on purchases), increased revenues to the organization, and mission-driven performance improvements.
- Customer Service Benefits, which include value added to products or services, improved response or timeliness, and improved customer experience.

For the following category, respondents were only asked to provide a qualitative estimate of the future annual benefits their program is likely to receive from having their 3D elevation data requirements met.

- Societal Benefits, which include education or outreach; environmental benefits; and public safety, including life and property.

For the quantitative estimates, respondents were asked to provide in either hours (annual or monthly) or as dollars. The options provided for answering the qualitative benefits questions in the online questionnaire were "Major," "Moderate," "Minor," "None," and "Don't know."

Tables 84 – 87 list the estimated quantitative future annual benefits as reported by study respondents.

Note that annual benefits provided by study respondents as monthly or annual hours saved were converted to dollars using the 2019 Bureau of Labor Statistics mean wage for federal, state, local government workers except schools, hospitals, post office; all occupations, of $30.15 per hour.[3]

5.5.1.1. Future Annual Benefits by Geography Type

Table 84 summarizes the reported future annual dollar benefits by geography type.

Table 84. Summary of reported future annual dollar benefits by geography type

Geography Type	Total Reported Future Annual Benefits
Inland Topography	$9.99B
Inland Bathymetry	$0.86B
Nearshore Bathymetry	$2.55B
Offshore bathymetry	$0.16B
Total	$13.56B

5.5.1.2. Future Annual Benefits by Organization Type

Table 85 summarizes the reported future annual dollar benefits by organization type.

Table 85. Summary of reported future annual dollar benefits by organization type

Organization Type	Total Reported Future Annual Benefits
Federal agencies	$5.84B
State, regional, county, local, and tribal government	$7.68B
Not-for-profit and private entities	$0.04B
Total	$13.56B

[3] https://www.bls.gov/oes/2019/may/naics2_99.htm

5.5.1.4. *Future Annual Benefits by Quality Level*

Table 86 summarizes the reported future annual dollar benefits by geography type and Quality Level. Note that maps showing reported future annual dollar benefits by geography type and Quality Level and update frequency are provided in Appendix J.

Table 86. Reported future annual dollar benefits by geography type and quality level

Inland Topography Quality Level	Total Reported Future Annual Dollar Benefits	Inland Bathymetry Quality Level	Total Reported Future Annual Dollar Benefits	Nearshore Bathymetry Quality Level	Total Reported Future Annual Dollar Benefits	Offshore Bathymetry Quality Level	Total Reported Future Annual Dollar Benefits
QL0HD	$2,246,804,952	QL0B	$194,456,321	QL0B	$2,274,720,161	Special Order	$13,509,642
QL0	$1,603,922,384	QL1B	$306,432,390	QL1B	$49,177,017	Order 1	$43,164,076
QL1HD	$659,745,643	QL2B	$210,941,446	QL2B	$127,383,522	Order 1a	$26,717,440
QL1	$1,851,264,690	QL3B	$4,245,733	QL3B	$747,540	Order 1b	$59,159,080
QL2	$3,364,564,846	QL4B	$6,818,367	QL4B	$8,219,074	Order 2	$10,543,682
Cross sections	$262,811,330	Cross sections	$137,877,187	Cross sections	$89,756,778	Cross sections	$10,050,449
I don't know	$23,114	I don't know	$1,733,036	I don't know	$765,307	I don't know	$784,554
Total	$9,989,136,958		$862,504,479		$2,550,769,398		$163,928,922

5.5.1.5. *Future Annual Benefits by Business Use*

Table 87 summarizes the reported future annual dollar benefits by Business Use.

Table 87. Summary of reported future annual dollar benefits by Business Use

Business Use	Total Reported Future Annual Benefits
BU 01 - Water Supply and Quality	$0.30B
BU 02 – Riverine Ecosystem Management	$0.07B
BU 03 - Coastal Zone Management	$4.35B
BU 04 - Forest Resources Management	$0.04B
BU 05 – Rangeland Management	$0.00B
BU 06 - Natural Resources Conservation	$0.72B
BU 07 - Wildlife and Habitat Management	$0.04B
BU 08 - Agriculture and Precision Farming	$0.01B
BU 09 - Fisheries Management and Aquaculture	$0.04B
BU 10 – Geologic Assessment and Hazard Mitigation	$0.87B
BU 11 - Geologic Resource Mining and Extraction	$0.03B
BU 12 - Renewable Energy Resources	$0.01B
BU 13 - Oil and Gas Resources	$0.02B
BU 14 - Cultural Resources Preservation and Management	$0.00B

Business Use	Total Reported Future Annual Benefits
BU 15 - Flood Risk Management	$1.66B
BU 16 - Sea Level Rise and Subsidence	$0.32B
BU 17 - Wildfire Management, Planning, and Response	$0.03B
BU 18 - Homeland Security, Law Enforcement, Disaster Response, and Emergency Management	$2.15B
BU 19 – Land Navigation and Safety	$0.05B
BU 20 - Marine and Riverine Navigation and Safety	$0.58B
BU 21 – Aviation Navigation and Safety	$0.07B
BU 22 - Infrastructure and Construction Management	$1.17B
BU 23 - Urban and Regional Planning	$0.82B
BU 24 - Health and Human Services	$0.00B
BU 25 - Real Estate, Banking, Mortgage, and Insurance	$0.04B
BU 26 - Education K-12 and Beyond, Basic Research	$0.08B
BU 27 - Recreation	$0.01B
BU 28 - Telecommunications	$0.00B
BU 29 - Military	$0.01B
BU 30 - Maritime and Land Boundary Management	$0.08B
Total	$13.56B

5.5.1.6. Qualitative Future Annual Benefits

Table 88 depicts the number of MCAs for which "Major" future annual benefits were reported for each benefit category and geography type.

Table 88. Intangible future annual benefits by geography type

Geography Type	Major Intangible Operational Benefits	Major Intangible Customer Service Benefits	Major Education & Outreach Benefits	Major Environ-mental Benefits	Major Public Safety and Other Benefits
Inland Topography	1,081	954	401	543	587
Inland Bathymetry	571	519	268	324	323
Nearshore Bathymetry	449	357	159	254	182
Offshore Bathymetry	204	171	76	133	117
Totals	2,305	2,001	904	1,254	1,209

5.6. Data Acquisition Costs

Estimated average cost information used in the BCRs and ROI Analyses was provided by USGS for lidar acquisition for Inland Topography and a combination of lidar acquisition and sonar for Inland Bathymetry. Topobathymetric lidar acquisition costs for Nearshore Bathymetry were averaged based on information provided by NOAA and the USACE. Costs for sonar collection for Offshore Bathymetry were inferred from publicly available past NOAA hydrographic services contract costs.

Acquisition costs are based on average estimated government contractor costs and include contractors' Quality Assurance/Quality Control (QA/QC) of their work, ensuring seamlessness within the task order area of interest, and core product generation. It does not include independent government validation of the contractors' work, derivative product generation, government IT costs for provisioning the data, or government contract management costs. See Section 7 and Appendix L on Program Management Lifecycle Considerations for a more thorough discussion of these activities.

5.6.1. Inland Topography

USGS provided cost estimates for the collection of topographic lidar for Inland Topography at QL0HD, QL0, QL1HD, QL1, QL2, and QL5. The costs for QL1 and QL2 are based on FY19 to FY21 3DEP cost estimates. The costs for QL0, QL1HD, and QL0HD are based on estimated increases above QL1 and QL0 costs. Additional acquisition factors were included for the increased mobilization costs for acquiring data in Alaska, Puerto Rico and the U.S. Virgin Islands, Hawaii, and other Pacific Islands. All costs are per square mile.

Additionally, an estimation of the difficulty to collect and process the data was applied to the continental U.S. (CONUS) costs. Difficulty factors include slope, canopy cover, other land cover, and urban density. Examples of the difficulty factors include:

- **Easy**: Little slope or canopy cover, no large urban or suburban areas;
- **Medium**: Low and medium density urban environments; medium slopes, 25-50% canopy cover; dense grasses; and
- **Hard**: Hard to process due to large urban environments; high slopes; evergreen forest, 50-100% canopy cover, wetlands.

These difficulty factors were applied spatially using 1/3 arc-second DEMs for terrain data to calculate slope and the National Land Cover Database (NLCD) to calculate canopy cover, wetlands, dense grasslands and urban density. Figure 29 shows an image of the resulting difficulty raster that was used for this estimate. Table 89 provides the resulting estimated calculations for collecting Inland Topography using lidar.

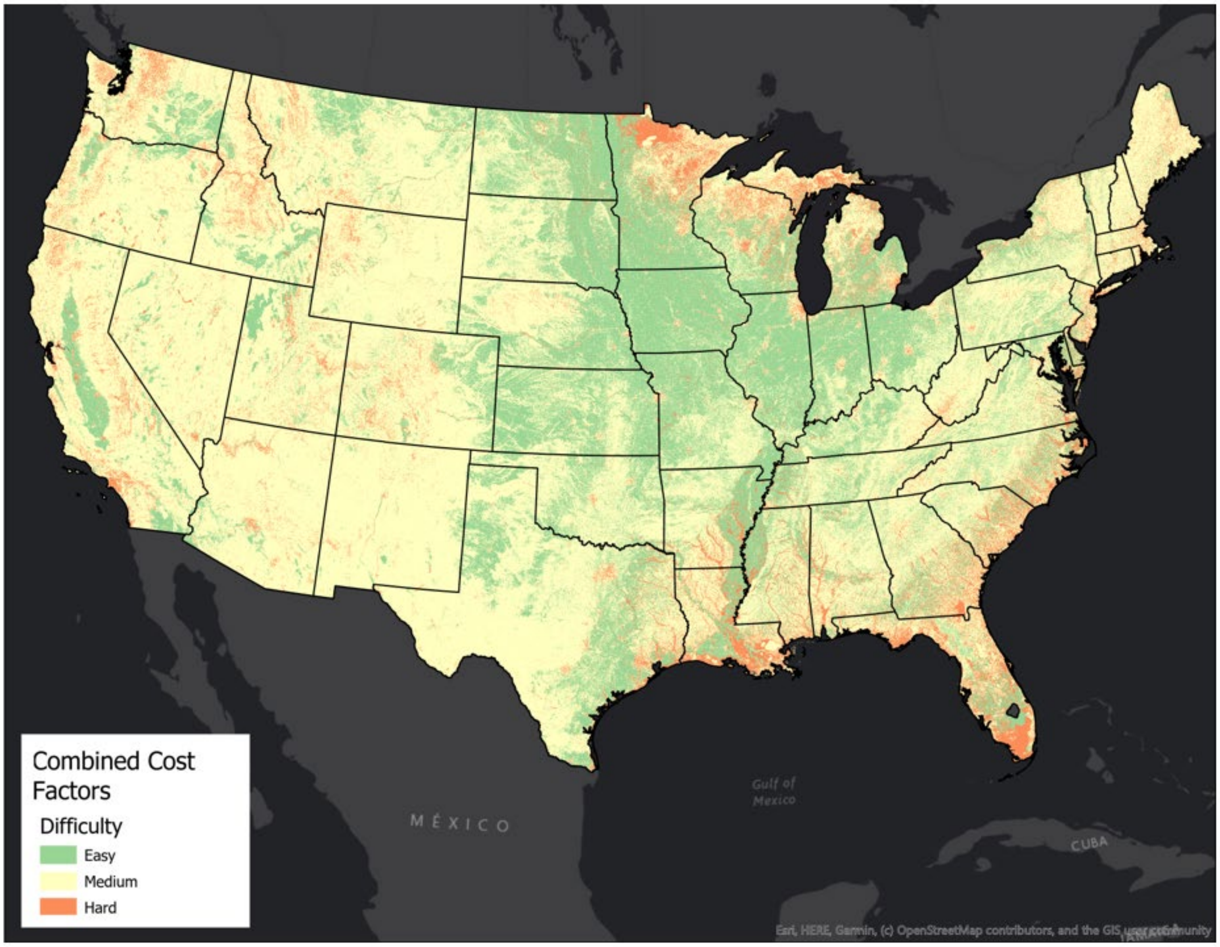


Figure 29. Difficulty level of collecting topographic lidar by 30-meter pixel

Table 89 depicts the estimated average costs to collect topographic lidar at varying Quality Levels, different parts of the U.S., and by difficulty level.

Table 89. Average estimated costs to collect topographic lidar per square mile

Quality Level	Lidar Cost/sq. mi. CONUS Easy	Lidar Cost/sq. mi. CONUS Medium	Lidar Cost/sq. mi. CONUS Hard	Lidar Cost/sq. mi. AK*	Lidar Cost/sq. mi. HI	Lidar Cost/sq. mi. Other Pacific Islands	Lidar Cost/sq. mi. PR & USVI
QL0HD	$663	$813	$1,068	$1,602	$2,136	$3,204	$1,335
QL0	$530	$650	$854	$1,281	$1,708	$2,562	$1,068
QL1HD	$441	$541	$711	$1,067	$1,422	$2,133	$889
QL1	$353	$433	$569	$854	$1,138	$1,707	$711
QL2	$190	$220	$325	$488	$650	$975	$406
QL5				$120			

* Average cost statewide. Coastal, extremely rugged terrain, and distant islands cost more than the mainland. Average also accounts for the difficulty of ground control surveys in remote areas.

5.6.2. Inland Bathymetry

USGS provided cost estimates for the collection of Inland Bathymetry based on two methods: topobathymetric lidar and sonar. Based on several pilot projects for the collection of Inland Bathymetry, USGS concluded that it would only be feasible to collect bathymetry using topobathymetric lidar on rivers in some areas of the U.S. The remaining areas would have to be collected using sonar. USGS also concluded that all lakes would have to be collected using sonar. For the purposes of this study, the Great Lakes are categorized as coastal and are not included in the Inland Bathymetry cost estimates. All topobathymetric lidar costs for rivers are based on collecting QL2B data. Sonar costs for rivers are based on collecting QL0B sonar and costs for collecting lakes are based on Order 1a sonar. All costs are per square mile.

To identify regions in the conterminous U.S. that would be most promising for accurate inland topobathymetric lidar data collection, physiographic characteristics and water transparency were taken into consideration. Physiographic provinces containing a majority bedrock permeability class of unconsolidated sand and gravel were considered unsuitable for inland bathymetric lidar, while physiographic provinces containing sandstone, semi-consolidated sand, basalt and other volcanic rocks, sandstone and carbonate rocks, or carbonate rock were considered to be more suitable.

In addition, NOAA's CoastWatch data portal was used to identify water clarity in order to visually validate conclusions regarding suitability of physiographic provinces in relation to bedrock permeability class. These data describe a quantification of turbidity using measurements that describe how strongly light intensity at a wavelength of 490 nanometers (nm) is attenuated within the water column, which is also known as the diffuse attenuation coefficient at 490 nm (K_d490). Waterbodies and rivers with higher K_d490 values (greater than about 0.8 K_d490), which represent smaller attenuation depth and lower water clarity, were primarily located in physiographic provinces determined to be the least promising for accurate inland bathymetric lidar, while waterbodies and rivers with lower K_d490 values (less than about 0.8 K_d490) were located in physiographic provinces determined to have conditions most favorable for inland bathymetric lidar data collection.

Generally, physiographic provinces and sections with low relief and that are known to contain large amounts of sand and sediment were determined to be the least promising for accurate inland bathymetric lidar for this analysis. These included the Atlantic Coastal Plain, Central Lowland, and Great Plains physiographic provinces. Several sections from the Central Lowland and Great Plains physiographic provinces were identified as being conducive for inland bathymetric lidar because those specific sections were determined to have higher relief, less sand and sediment, and riverbed substrate more suitable for inland bathymetric lidar than other sections in those physiographic provinces.

Figure 30 shows an image of the physiographic regions considered to be conducive to collecting Inland Bathymetry using topobathymetric lidar for this analysis. Tables 90 – 92 provide the resulting estimated cost calculations for Inland Bathymetry.

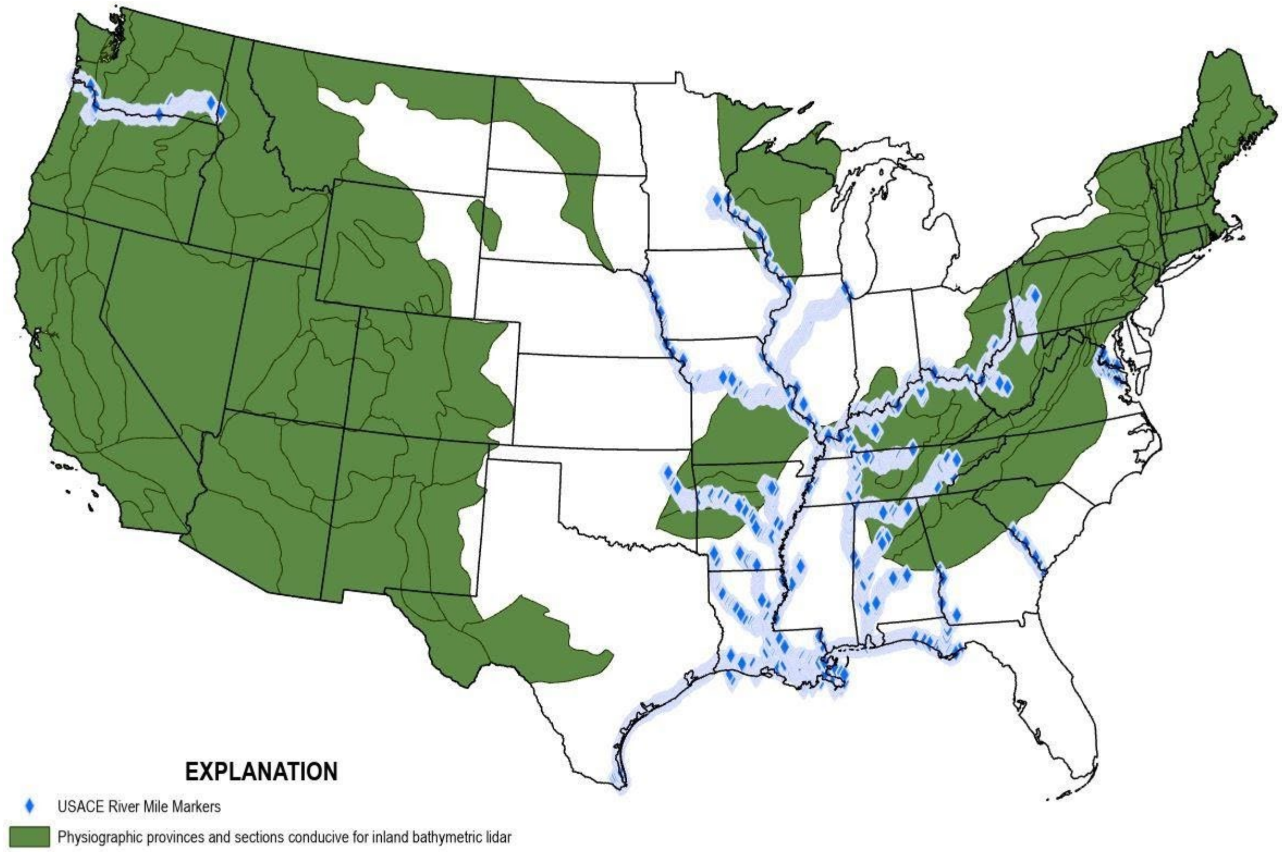


Figure 30. Physiographic regions conducive to collecting Inland Bathymetry with topobathymetric lidar

Table 90 depicts the average estimated costs to collect Inland Bathymetry for rivers in regions that are considered to be conducive to collection using topobathymetric lidar.

Table 90. Estimated costs for collecting Inland Bathymetry using topobathymetric lidar for rivers

Cost Basis	Topobathymetric Lidar Average Cost/sq. mi.	Low	High	Minimum	Maximum
Linear Mile	$2,600	$2,400	$2,600	$1,800	$4,200
Square Mile	$5,700	$4,600	$7,000	$2,200	$16,600

Table 91 depicts the average estimated cost per square mile to collect Inland Bathymetry using sonar for rivers in regions that are considered not to be conducive to collection using topobathymetric lidar.

Table 91. Estimated costs for collecting Inland Bathymetry using sonar for rivers

River Width (Feet)	Non-Navigable Rivers Sonar Cost/sq. mi.	Navigable Rivers Sonar Cost/sq. mi.
0 – 100	$88,176.00	$71,280.00
100 -700	$26,758.29	$19,366.29
700 – 5,280	$12,463.50	$10,273.50

Table 92 depicts the average estimated costs to collect Inland Bathymetry using sonar for all lakes and ponds shown in the National Hydrography Database in the U.S.

Table 92. Estimated costs for collecting Inland Bathymetry using sonar for lakes and ponds

Lake Size	Lake Area (sq. mi.)	Sonar Cost/acre	Sonar Cost/sq. mi.
Small	0 – 10	$100	$64,000
Medium	10 - 50	$54	$34,560
Large	>50	$8	$5,120

5.6.3. Nearshore Bathymetry

NOAA provided cost estimates for the collection of Nearshore Bathymetry using topobathymetric lidar. These costs are based on average historic contracting costs from both NOAA and USACE. Cost ranges were provided for CONUS, with additional factors applied to account for the increased mobilization costs for acquiring data in Alaska and the Pacific Islands. All costs are per square mile. Table 93 provides the cost ranges for Nearshore Bathymetry collected with topobathymetric lidar. Table 94 provides cost ranges for deriving Nearshore Bathymetry using SDB.

Table 93 depicts the average estimated cost per square mile to collect topobathymetric lidar for U.S. nearshore waters.

Table 93. Average estimated costs to collect Nearshore Bathymetry using topobathymetric lidar

Location	Topobathymetric Lidar Cost Range/sq. mi.
CONUS, Puerto Rico, U.S. Virgin Islands	$2,500 - $3,500
Alaska, Pacific Islands	$3,000 - $5,000

Table 94 depicts the average estimated cost per square mile to derive bathymetry from satellite data at three different raster cell sizes GSD for U.S. nearshore waters.

Table 94. Average estimated costs to collect Nearshore Bathymetry using Satellite Derived Bathymetry

Satellite Derived Bathymetry GSD	Satellite Derived Bathymetry Cost Range/sq. mi	Satellite Derived Bathymetry Average Cost/sq. mi
2 m GSD	$130 - $328	$220
5 m GSD	$60 - $100	$80
10-30 m GSD	$23 - $60	$42

5.6.4. Offshore Bathymetry

Costs for sonar collection for Offshore Bathymetry were inferred from past NOAA hydrographic services contract costs. All acquisition costs are based on hydrographic surveys using MBES and include collection of bathymetry and sidescan for water depths in the Gulf of Mexico, Bering Sea, North Slope of Alaska, and New England.

5.5.4.1. Order 1a Costs

Publicly available contract costs for Order 1a hydrographic survey collections were used to estimate costs for sonar collection for Nearshore Bathymetry. NOAA provided public domain spatial data showing the areas of interest for specific projects as well as survey number, project number, year, contractor, and region. NOAA also provided public domain contracting costs for fiscal years 2015 – 2019. Dewberry was able to marry these data and extract information about the costs per linear nautical mile (LNM) and SNM for specific hydrographic survey projects. The majority of these projects fell within the Gulf of Mexico, with only a few along the Atlantic coast and Alaska, and one on the Pacific coast. Therefore, it should be noted that the Order 1a costs for deeper waters are based on only a few datapoints per depth bin.

Actual contract costs were calculated per LNM, then these costs were averaged and applied to the entire EEZ. Based on input from NOAA, 120-meter set line spacing for side scan sonar operations in water depths up to 20 meters is assumed for all of the east coast, Gulf of Mexico, Bering Sea (north of the Aleutian Chain), North Slope of Alaska, and the New England coast. Elsewhere, MBES collection is assumed with swath spacing based on depth.

For the areas where swath spacing based on depth was used, Dewberry estimated LNMs per Greenaway, et al. 2020.[4]

As shown in Figure 31, MBES swath widths decrease as water depth decreases, therefore costs increase dramatically because the number of passes needed to collect full bottom coverage

[4] Are We Done Yet? An Empirical Estimator for Level of Effort for Seafloor Surveys - Including an Estimate for the Full Survey of U.S. Waters: Marine Geodesy: Vol 43, No 2 (tandfonline.com)

increases. Depth bands derived from the General Bathymetric Chart of the Ocean (GEBCO) 2020 grid[5] were used to estimate average costs per SNM.

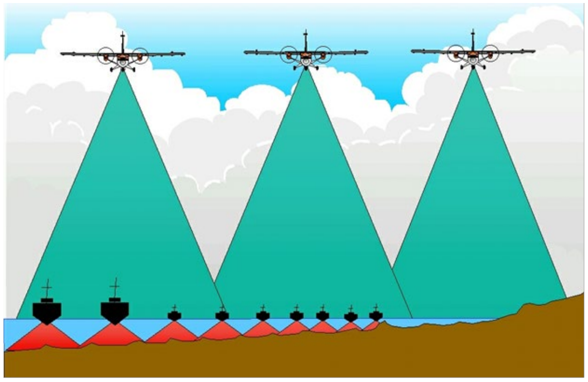


Figure 31. From the DEM Users Manual, 3rd edition, this figure shows how swath width increases with depth, illustrating why it is more costly to map in shallower waters because more passes are needed to map the same bottom area.

Figure 32 depicts a ship using a MBES to collect bathymetry.

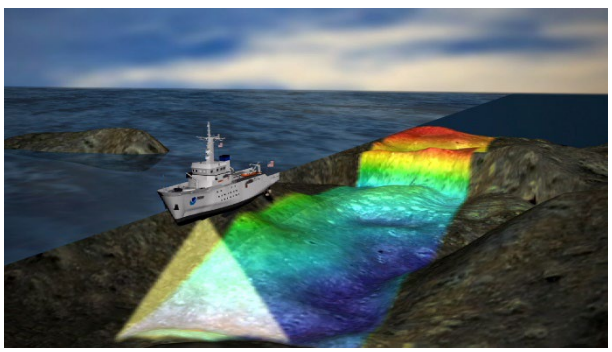


Figure 32. Multi-beam echosounder. Image source: NOAA

Table 95 depicts the estimated average estimated cost per SNM to collect Order 1a bathymetric data using MBES for U.S. offshore waters.

Table 95. Average estimated costs by depth to collect Offshore Bathymetry at Order 1a Quality Level using multi-beam echo sounder

Depth Range (meters)	Order 1a Average Cost/SNM
10.1 to 20.0	$30,071
20.1 to 40.0	$13,554
40.1 to 60.0	$8,143
60.1 to 80.0	$5,723
80.1 to 100.0	$4,405
100.1 to 200.0	$2,948

[5] https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_2020/

Depth Range (meters)	Order 1a Average Cost/SNM
200.1 to 500.0	$1,329
500.1 to 1000.0	$539
>1000.0	$103

5.5.4.2. Order 2 Costs

Dewberry inferred Order 2 sonar cost information from publicly available information about daily vessel rates as well as the average LNM per day that could be collected by a large vessel. Per IHO specification, line spacing in deeper waters is four times the depth. Based on this input, the range of cost per day for a vessel is between $30,000 to $50,000 per day with an average of $35,000 per day. An average of 175-200 LNM can be collected per day.

Unmanned systems (i.e., uncrewed surface vessels) are becoming more widely used as a force multiplier for hydrographic survey missions. NOAA provided information indicating that a four-fold increase in LNM collection per day could be achieved using UxSs. Note that several private companies are focusing on developing UxSs for use as stand-alone collection systems. It is expected that may boost future acquisitions at significantly lower costs if the need for crewed vessels and their associated costs can be reduced or eliminated.

Table 96 depicts the estimated average estimated cost per SNM to collect Order 2 bathymetric data using MBES for the offshore waters of the U.S. that are deeper than 100 meters.

Table 96. Average estimated costs by depth to collect Offshore Bathymetry at Order 2 Quality Level

Depth Range (meters)	Order 2 Average Cost/SNM	Cost/SNM with UxS as Force Multiplier
100.1 to >1000.0	$59.40	$14.85

5.6. Reduced Value Multipliers

Recognizing that benefits are unrealized if users do not receive the Quality Level and update frequency required, Dewberry applied a procedure for degrading annual dollar benefits with reduced *value multipliers* explained below.

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

The following method was used to determine the benefits that would be realized for each MCA for multiple program implementation scenarios. The scenarios include implementing various combinations of Quality Levels and update frequencies. For each scenario, a determination is made as to whether it meets the needs of each MCA. If it does, 100 percent of the benefits are realized. If not, a percentage of the benefits is applied as follows.

5.6.1. Update Frequency Reduced Value Multipliers

If the provided update frequency for the option is poorer than the required update frequency for the MCA, the resulting benefits are calculated by multiplying the benefits by a value multiplier (fraction) specified for each reduction of update frequency as shown in Table 97.

Table 97 depicts the reduced value multipliers for update frequency used in the BCAs.

Table 97. Update frequency reduced value multipliers

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

If the required update frequency is "event driven," the *value multiplier* is 50 percent since event driven requirements pertain to the need for elevation data both before and after an event in order to determine the changes caused by the event. A national program could provide the pre-event data, but post-event data would still be required.

5.6.2. Quality Level Reduced Value Multipliers

If the provided Quality Level for the option is greater than the required Quality Level, the benefits are multiplied by a percent specified for each reduction of Quality Level as shown in Tables 98 – 100. The Quality Level degradation factors are based on the relative cost ratios between the Quality Levels which vary by acquisition method and geography type.

Table 98 depicts the reduced value multipliers for Quality Level used in the BCAs for Inland Topography.

Table 98. Quality level reduced value multipliers for Inland Topography

Needed Inland Topography Quality Level	Provided Inland Topography Quality Level				
	QL0HD	**QL0**	**QL1HD**	**QL1**	**QL2**
QL0HD	100%	80%	70%	50%	30%
QL0	100%	100%	83%	66%	36%
QL1HD	100%	100%	100%	80%	43%
QL1	100%	100%	100%	100%	54%
QL2	100%	100%	100%	100%	100%

Table 99 depicts the reduced value multipliers for Quality Level used in the BCAs for Inland and Nearshore Bathymetry.

Table 99. Quality level reduced value multipliers for Inland and Nearshore Bathymetry

Needed Inland and Nearshore Bathymetry Quality Level	Provided Inland and Nearshore Bathymetry Quality Level					
	QL0B	QL1B	QL2B	SDB 2 m GSD (QL3B)	SDB 5 m GSD (QL4B)	SDB 10 m GSD (QL4B)
QL0B	100%	85%	99%	72%	50%	50%
QL1B	100%	100%	100%	98%	83%	83%
QL2B	100%	100%	100%	84%	70%	70%
QL3B	100%	100%	100%	100%	84%	84%
QL4B	100%	100%	100%	100%	100%	100%

Table 100 depicts the reduced value multipliers for Quality Level used in the BCAs for Offshore Bathymetry.

Table 100. Quality level reduced value multipliers for Offshore Bathymetry

Needed Offshore Bathymetry IHO Order	Provided Offshore Bathymetry IHO Order				
	Special Order	Order 1a	Order 1b	Order 2	Order 3
Special Order	100%	80%		64%	
Order 1a	100%	100%		80%	
Order 1b	100%	100%		80%	
Order 2	100%	100%		100%	
Order 3	100%	100%		100%	

5.7. Benefit Cost Analyses

Three widely used methods for performing BCAs are: (1) Net Benefits where costs are subtracted from the benefits (Net Benefits = benefits minus costs); (2) BCR where the benefits are divided by the costs (BCR = benefits/costs); and (3) ROI where the net benefits are divided by the costs and expressed as a percentage (ROI = (net benefits/costs)÷100. All three methods were calculated for the 3D Nation Study BCAs.

Benefit Cost Analyses were run for a range of nationwide uniform Quality Levels and update frequencies for each of the geography types as well as some combinations of Quality Levels and update frequencies that varied spatially. A summary of the results of the analyses are provided in the section titled "Benefit Cost Results." The detailed results of the analyses are provided in Appendix K. Additional program scenarios may be analyzed using discount rates as described in OMB Circular A-94. Those results would be published separately.

5.7.2. Inland Topography

Since cost information was provided nationwide for all Quality Levels that were included in the 3D Nation Study questionnaire, nationwide analyses were performed for the 25 uniform Quality Level and update frequency combinations. In addition, analyses were requested for several combinations of Quality Levels and update frequencies. Many respondents requested higher Quality Level and/or update frequencies in urban, forested, and coastal areas. For the analyses of mixed Quality Levels and/or update frequencies, the following data were used. USGS provided a raster derived from the NLCD with specific areas identified for different Quality Levels and update frequencies. The urban areas used for the analyses were derived from Census 2010 Urbanized Areas and Urban Clusters provided in an Esri feature service. The forested areas were derived from data provided by the USFS. A two-mile buffer inland of the shoreline was used to represent the coastal areas for analysis.

Table 101 depicts the Quality Level and update frequency combinations that were analyzed for Inland Topography.

Table 101. Inland Topography Quality Level and update frequency scenarios analyzed

Inland Topography Quality Level	Inland Topography Update Frequency				
QL0HD	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL0	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL1HD	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL1	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL1 in coastal areas, based on the raster elsewhere			4-5 years		
QL1		2 years in coastal areas, based on the raster elsewhere	5 years based on the raster	8 years based on the raster	
QL2		2 years in coastal areas, based on the raster elsewhere	5 years based on the raster	8 years based on the raster	
QL2		2 years in urban and coastal areas	5 years elsewhere		
QL1 in coastal, urban, and forested areas; QL2 elsewhere		2-3 years in urban and coastal areas	4-5 years in elsewhere		
3DEP Status Quo (AK QL5, QL2 elsewhere)				6-10 years	
QL2 AK, QL1 elsewhere			4-5 years		

5.7.3. Inland Bathymetry

Acquisition cost information was provided for QL2B topobathymetric lidar and QL0B sonar for Inland Bathymetry. As noted above in the discussion of costs, it is assumed that all lakes and ponds will require sonar collection as will some rivers. Different combinations of the areas used to calculate the acquisition costs were used for the Inland Bathymetry BCAs.

Table 102 depicts the Quality Level and update frequency combinations that were analyzed for Inland Bathymetry.

Table 102. Inland Bathymetry quality level and update frequency scenarios analyzed

Inland Bathymetry Quality Level	Inland Bathymetry Update Frequency				
QL0B in all sonar areas and QL2B in all lidar areas	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL0B in all sonar areas only	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in all lidar suitable areas only	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL0B in large lakes >50 sq. mi.	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL0B in large and medium lakes >10 sq. mi.	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL0B in all lakes				6-10 years	
QL0B in navigable channels (rivers) only				6-10 years	
QL0B in non-navigable rivers only				6-10 years	

5.7.4. Nearshore Bathymetry

Acquisition cost information was provided for QL2B topobathymetric lidar for Nearshore Bathymetry. In addition to nationwide analyses for QL2B at the different update frequencies, a scenario for more frequent updates in and around ports and harbors was analyzed as well as ones that examined only the areas identified as priority areas[6] by the different federal agencies that participated in the IWG-OCM 2021 prioritization survey.

[6] Note that in the IWG-OCM 2021 prioritization survey, respondents were able to choose grid cells that covered the nearshore and offshore areas of the U.S. and indicate the type of data needed, its horizontal resolution, and its priority. The following definitions were used for the priorities: High (mapping needed in 1-2 years), Medium (mapping needed in 4-5 years), Low (mapping needed in 6-10 years), and None (mapping may be needed but not within 10 years). The Nearshore Bathymetry and Offshore Bathymetry scenarios considered for this study accounted for grid cells where topography or bathymetry were needed with a priority of High, Medium, or Low.

A lower cost option using SDB for the depth band of 0-10 meters was also analyzed. Three different satellite imagery sources at differing GSD were examined with the assumption of a one-time only collection for each since it would only represent a "best available" option until such time as data with higher accuracy could be acquired.

Table 103 depicts the Quality Level and update frequency combinations that were analyzed for Nearshore Bathymetry.

Table 103. Nearshore bathymetry quality level and update frequency scenarios analyzed

Nearshore Bathymetry Quality Level	Nearshore Bathymetry Update Frequency				
QL2B	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B			Ports and harbors 5 years	10 years elsewhere	
QL2B in IWG-OCM 2021 federal priority areas only - BOEM	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in IWG-OCM 2021 federal priority areas only - DOE	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in IWG-OCM 2021 federal priority areas only - EPA	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in IWG-OCM 2021 federal priority areas only - NOAA	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in IWG-OCM 2021 federal priority areas only - NPS	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in IWG-OCM 2021 federal priority areas only - USCG	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in IWG-OCM 2021 federal priority areas only - USDA	Annual	2-3 years	4-5 years	6-10 years	>10 years
QL2B in IWG-OCM 2021 federal priority areas only - USGS	Annual	2-3 years	4-5 years	6-10 years	>10 years
Satellite Derived Bathymetry at 10-30m GSD, 0-10 m depth					>10 years
Satellite Derived Bathymetry at 5m GSD, 0-10 m depth					>10 years
Satellite Derived Bathymetry at 2m GSD, 0-10 m depth					>10 years
QL2B, no collection in Pacific Island territories	Annual	2-3 years	4-5 years	6-10 years	>10 years

5.7.5. Offshore Bathymetry

Acquisition cost information was provided for Order 1a and Order 2 hydrographic survey data for Offshore Bathymetry. In addition to nationwide analyses for Order 1a the five different update frequencies, scenarios for update frequencies of 30 years and 100 years were analyzed. Additionally, scenarios for specific depth bands were analyzed, as were scenarios based on NOAA's HHM priorities, which are based on navigational risks, as well as ones that examined only the areas identified as priority areas by the different federal agencies that participated in the IWG-OCM 2021 prioritization survey.

Scenarios that combined Order 1a for waters 10-100 meters deep and Order 2 in waters greater than 100 meters deep were also analyzed for the five different update frequencies. Scenarios that added UxSs (i.e., uncrewed surface vessels) as a force multiplier for hydrographic survey missions were also examined.

Finally, since so many respondents who require offshore bathymetry were unable to estimate dollar benefits for their MCAs, NOAA was interested in understanding how cost avoidance as a benefit might affect the results. For this scenario, one-time data acquisition for Order 1a data was calculated for the entire EEZ. Any benefits reported for the categories of "Data acquisition costs saved, reduced, or available to spend on other projects" and "Data processing avoided (e.g., classifying point clouds, QC, hydrotreatment, etc.)" were subtracted from the acquisition costs. This was then added as an assumed benefit that was spread across all of the Offshore Bathymetry area of interest.

Table 104 depicts the Quality Level and update frequency combinations that were analyzed for Offshore Bathymetry.

Table 104. Offshore bathymetry quality level and update frequency scenarios analyzed

Offshore Bathymetry Quality Level	Offshore Bathymetry Update Frequency				
Order 1a	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a 10-40 m depth					>10 years
Order 1a 40-200 m depth				6-10 years	
Order 1a in HHM: Navigationally Significant areas			4-5 years	6-10 years	
Order 1a in HHM: Desired Survey Score = 100 (Object Detection)		2-3 years			
Order 1a in HHM: Desired Survey Score = 80 (Complete Coverage)			4-5 years		
Order 1a in HHM: Desired Survey Score = 30 (Partial Bottom Coverage)				6-10 years	
Order 1a in HHM: Desired Survey Score = 10 (Lesser)					>10 years
Order 1a in HHM: Hydro Gap = 0 (No gap)				6-10 years	
Order 1a in HHM: Hydro Gap = 0.1-25 (Small gap)				6-10 years	
Order 1a in HHM: Hydro Gap = 25.1-50 (Medium gap)				6-10 years	

Offshore Bathymetry Quality Level	Offshore Bathymetry Update Frequency				
Order 1a in HHM: Hydro Gap = 50.1-75 (Medium large gap)				6-10 years	
Order 1a in HHM: Hydro Gap = >75 (Large gap)				6-10 years	
Fill bathy gap analysis gaps				6-10 years	
Order 1a 10-20 m depth	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a 20-40 m depth	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a 40-100 m depth	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a 100-500 m depth	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a >500 m depth	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - BOEM	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - DOE	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - EPA	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - NOAA	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - NPS	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - USCG	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - USDA	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a in IWG-OCM 2021 federal priority areas only - USGS	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a 1x in 100 years					100 years
Order 1a 1x in 30 years					30 years
Order 1a 40 m and greater depth (NOMEC Strategy)					1x by 2030
Order 1a 10-40 m depth (NOMEC Strategy)					1x by 2040
Order 1a 10-100 m depth, Order 2 >100m depth	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a 10-100 m depth, Order 2 >100m depth, UxS as force multiplier	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a with Cost Avoidance	Annual	2-3 years	4-5 years	6-10 years	>10 years
Order 1a, no collection in Pacific Island territories	Annual	2-3 years	4-5 years	6-10 years	>10 years

Offshore Bathymetry Quality Level	Offshore Bathymetry Update Frequency				
Order 1a 40 m and greater depth (NOMEC Strategy) with cost avoidance					1x by 2030
Order 1a 10-4 0m depth (NOMEC Strategy) with cost avoidance					1x by 2040

5.8. Benefit Cost Analysis Results

As noted above, BCAs were performed on a range of nationwide Quality Level and update frequency combinations. The analyses were calculated using: (1) Net Benefits where Net Benefits = benefits minus costs; (2) BCR where BCR = benefits/costs; and (3) ROI where ROI = net benefits/cost ÷ 100. The detailed results of the analyses are provided in Appendix K.

Benefit Cost Ratios prioritize lower costs but do not necessarily provide the highest benefits. Net benefits prioritize benefits but those scenarios with higher net benefits may cost more.

5.8.1. Inland Topography

Nationwide BCAs were performed on the 25 uniform Quality Level and update frequency combinations for Inland Topography. In addition, analyses were requested for several other combinations of Quality Levels and update frequencies. Three mixed-use scenarios were also evaluated. One mixed-use scenario evaluated QL1 data in coastal areas and areas identified by USGS in a raster as developed or urban, wetland, or forested with denser canopies; QL2 elsewhere; and an update frequency of 4-5 years. Another mixed-use scenario evaluated QL2 data everywhere but an update frequency of 2-3 years in the coastal and developed or urban areas, 4-5 years in areas with forests or wetlands, and 6-10 years elsewhere. The third mixed-use scenario evaluated QL1 data everywhere but an update frequency of 2-3 years in the coastal and developed or urban areas, 4-5 years in areas with forests or wetlands, and 6-10 years elsewhere.

Table 105 depicts the results of the Inland Topography BCAs ranked by the BCR .

All scenarios evaluated provide a positive BCR and positive net benefits. Based on the highest BCR, the scenarios that cost the least because they either deliver lower quality data or the costs are spread over a longer period (e.g., update frequencies of >10 years) rank highest. Thus, QL2 data with an update frequency of >10 years provides the highest BCR . While this might be the most cost-effective future program, it is actually not better than the current 3DEP program and may not be a wise choice for 3DEP to pursue.

Based on the highest net benefits, the scenarios that provide the highest benefits would deliver the highest quality of data or are refreshed most frequently. QL0HD data updated every 4-5 years was documented to provide the highest net benefits. However, a national program for QL0HD data may not prove to be affordable or achievable in the long run. Therefore, an option in the middle that balances the BCR and net benefits may be the best option.

Table 105. Inland Topography Benefit/Cost results

Quality Level	Update Frequency	Annual Total Benefits	Cost Per Year	Benefit/Cost Ratio	Net Benefits (Benefits/Costs)
QL2	>10 years	$4,273,712,745	$63,762,080	67.03	$4,209,950,664
3DEP Status Quo (AK QL5, QL2 elsewhere)	6-10 years	$4,543,046,465	$92,539,693	49.09	$4,450,506,771
QL2	6-10 years	$5,320,169,773	$119,553,901	44.50	$5,200,615,872
QL1	>10 years	$5,286,825,420	$118,971,705	44.44	$5,167,853,715
QL1HD	>10 years	$5,713,813,883	$148,645,002	38.44	$5,565,168,880
QL2	Coastal 2 years, based on the raster elsewhere	$5,812,430,121	$158,615,305	36.64	$5,653,814,817
QL1 coastal areas, based on the raster elsewhere	4-5 years	$7,441,119,272	$212,958,915	34.94	$7,228,160,357
QL0	>10 years	$5,962,487,533	$178,558,593	33.39	$5,783,928,940
QL2	4-5 years	$6,882,761,956	$212,540,269	32.38	$6,670,221,687
QL1	6-10 years	$6,333,282,449	$223,071,947	28.39	$6,110,210,501
QL0HD	>10 years	$6,187,168,028	$223,327,944	27.70	$5,963,840,083
QL2	Coastal and urban areas 2 years, 5 years elsewhere	$7,328,465,585	$277,377,206	26.42	$7,051,088,379
QL1HD	6-10 years	$6,760,270,911	$278,709,379	24.26	$6,481,561,532
QL2 AK, QL1 elsewhere	4-5 years	$7,862,334,502	$349,357,331	22.51	$7,512,977,171
QL1	Coastal 2 years, based on the raster elsewhere	$6,318,986,459	$295,513,641	21.38	$6,023,472,818
QL0	6-10 years	$7,008,944,561	$334,797,362	20.93	$6,674,147,199
QL1	4-5 years	$7,895,874,632	$396,572,351	19.91	$7,499,302,281
QL2	2-3 years	$7,318,071,650	$382,572,485	19.13	$6,935,499,165
QL0HD	6-10 years	$7,233,625,057	$418,739,896	17.27	$6,814,885,160
QL1 urban, forested, and coastal areas; QL2 elsewhere	Coastal and urban areas 2-3 years, 4-5 years elsewhere	$7,691,914,300	$449,543,767	17.11	$7,242,370,534
QL1HD	4-5 years	$8,322,863,094	$495,483,340	16.80	$7,827,379,753
QL0	4-5 years	$8,571,536,744	$595,195,311	14.40	$7,976,341,433
QL0HD	4-5 years	$8,796,217,240	$744,426,482	11.82	$8,051,790,757
QL1	2-3 years	$8,331,184,326	$713,830,232	11.67	$7,617,354,093
QL1HD	2-3 years	$8,758,172,788	$891,870,013	9.82	$7,866,302,774

Quality Level	Update Frequency	Annual Total Benefits	Cost Per Year	Benefit/Cost Ratio	Net Benefits (Benefits/Costs)
QL0	2-3 years	$9,006,846,438	$1,071,351,560	8.41	$7,935,494,878
QL2	Annual	$7,936,429,722	$956,431,213	8.30	$6,979,998,509
QL0HD	2-3 years	$9,231,526,934	$1,339,967,669	6.89	$7,891,559,264
QL1	Annual	$8,949,542,397	$1,784,575,581	5.01	$7,164,966,816
QL1HD	Annual	$9,376,530,860	$2,229,675,033	4.21	$7,146,855,826
QL0	Annual	$9,625,204,510	$2,678,378,901	3.59	$6,946,825,608
QL0HD	Annual	$9,849,885,005	$3,349,919,172	2.94	$6,499,965,832

5.8.2. Inland Bathymetry

QL2B topobathymetric lidar and QL0B sonar were analyzed for Inland Bathymetry. It was assumed that all lakes and ponds will require sonar collection as will some rivers. Different combinations of the areas used to calculate the acquisition costs were used for the Inland Bathymetry BCAs.

Table 106 depicts the results of the nationwide Inland Bathymetry BCAs ranked by the BCR. Note that additional scenarios that do not provide nationwide coverage of Inland Bathymetry were also analyzed. Those results are shown in Appendix K.

The three scenarios with update frequencies greater than 2-3 years all provide a positive BCR and net benefits. Based on both the highest BCR and the highest net benefits, the scenarios where the costs are spread over a longer period rank highest. Since only one Quality Level was analyzed, only the update frequency influenced the results.

Table 106. Inland Bathymetry Benefit/Cost results for nationwide coverage

Quality Level	Update Frequency	Annual Total Benefits	Cost Per Year	Benefit/Cost Ratio	Net Benefits (Benefits/Costs)
QL0B sonar areas, QL2B lidar areas	>10 years	$567,680,429	$233,619,067	2.43	$334,061,361
QL0B sonar areas, QL2B lidar areas	6-10 years	$688,218,250	$438,035,752	1.57	$250,182,499
QL0B sonar areas, QL2B lidar areas	4-5 years	$794,925,663	$778,730,225	1.02	$16,195,438
QL0B sonar areas, QL2B lidar areas	2-3 years	$849,782,041	$1,401,714,405	0.61	-$551,932,364
QL0B sonar areas, QL2B lidar areas	Annual	$850,682,801	$3,504,286,012	0.24	-$2,653,603,212

5.8.3. Nearshore Bathymetry

The primary Quality Level analyzed for Nearshore Bathymetry was QL2B because that is what is collected using the current topobathymetric lidar sensors. In addition to nationwide analyses for QL2B at the different update frequencies, a scenario for more frequent updates in and around ports and harbors was analyzed as well as ones that examined only the areas identified as priority areas by the different federal agencies that participated in the IWG-OCM 2021 prioritization survey.

A lower cost option using SDB for the depth band of 0-10 meters was also analyzed. Three different satellite imagery sources at differing GSD were examined with the assumption of a one-time only collection for each.

Table 107 depicts the results of the nationwide Nearshore Bathymetry BCAs ranked by the BCR . Note that additional scenarios that may not provide nationwide coverage of Nearshore Bathymetry were also analyzed. Those results are shown in Appendix K.

All scenarios evaluated provide a positive BCR and net benefits. Based on the highest BCR , the scenarios that cost the least because they either deliver lower quality data (e.g., SDB) or the costs are spread over a longer period (e.g., update frequencies of >10 years) rank highest. The SDB options provide the highest BCR. While this might be the most cost-effective future program, the Quality Level is worse than the current NOAA and JALBTCX topobathymetric collection programs and specification and would not be a wise choice for a national program.

Based on the highest net benefits, the scenarios that provide the highest benefits because they are refreshed most frequently rank the highest. Thus, QL2B data updated annually provides the highest net benefits. While this may provide the highest benefits, annual updates are unlikely to be affordable or achievable in the long run. Therefore, an option in the middle that balances the BCR and net benefits may be the best option.

Table 107. Nearshore Bathymetry Benefit/Cost results

Quality Level	Update Frequency	Annual Total Benefits	Cost Per Year	Benefit/Cost Ratio	Net Benefits (Benefits/Costs)
SDB 10 m GSD (QL3B)	One time only	$812,020,818	$282,530	2,874.11	$811,738,288
SDB 5 m GSD (QL4B)	One time only	$812,020,818	$538,152	1,508.91	$811,482,666
SDB 2 m GSD (QL4B)	One time only	$1,074,882,091	$1,479,917	726.31	$1,073,402,174
QL2B	>10 years	$1,392,624,929	$17,702,002	78.67	$1,374,922,926
QL2B	6-10 years	$1,515,653,656	$33,191,254	45.66	$1,482,462,402
QL2B	Ports & harbors* 5 years, elsewhere 10 years	$1,059,863,307	$27,098,813	39.11	$1,032,764,493
QL2B	4-5 years	$1,713,643,971	$59,006,674	29.04	$1,654,637,297
QL2B	2-3 years	$2,025,781,752	$106,212,014	19.07	$1,919,569,738
QL2B	Annual	$2,537,591,783	$265,530,035	9.56	$2,272,061,747

*Note: The port shapefile used for this analysis is not authoritative and is intended for planning purposes only.

5.8.4. Offshore Bathymetry

Order 1a and Order 2 hydrographic survey data were analyzed for Offshore Bathymetry. In addition to nationwide analyses for Order 1a with the five different update frequencies, scenarios for update frequencies of 30 years and 100 years were analyzed, and scenarios that represent the NOMEC Strategy were analyzed. Additionally, scenarios for specific depth bands were analyzed, as were scenarios based on NOAA's HHM priorities, which are based on navigational risks, as well as ones that examined only the areas identified as priority areas by the different federal agencies that participated in the IWG-OCM 2021 prioritization survey.

Although industry response on Offshore Bathymetry requirements and benefits was low, contributing to an undercount by study respondents, scenarios that combined Order 1a for waters 10-100 meters deep and Order 2 in waters greater than 100 meters deep were also analyzed for the five different update frequencies. Additionally, scenarios that added UxSs (i.e., uncrewed surface vessels) as a force multiplier for hydrographic survey missions were examined.

Finally, NOAA was interested in understanding how cost avoidance as a benefit might affect the results as well as what the impacts would be if the islands in the Pacific territories were not included in the acquisitions.

Table 108 depicts the results of the nationwide Offshore Bathymetry BCAs ranked by the BCR. Note that additional scenarios that may not provide nationwide coverage of offshore bathymetry were also analyzed. Those results are shown in Appendix K.

The scenarios that provide a positive BCR Ratio and positive net benefits are those that assume cost avoidance as an added benefit, those that combine the Nearshore Bathymetry and Offshore Bathymetry portions of the NOMEC Strategy, and the one that spreads the costs over 100 years.

Based on the highest BCR and the highest net benefits, the scenarios that spread the costs over the longest period rank highest. The scenario that spreads the costs over 100 years and assumes cost avoidance as a benefit provides the highest BCR. However, that timeline does not meet current Administration goals as outlined in the NOMEC Strategy (i.e., full bottom coverage to the EEZ by 2040).While this may be the most cost-effective future program direction, it may not be the wisest choice for a national program that seeks to improve the mapping, exploration and characterization of the EEZ for more efficient permitting of ocean exploration, mapping, and research activities.

All NOMEC Strategy scenarios where Nearshore and Offshore Bathymetry areas are combined provide a positive BCR and net benefits. Based on the highest BCR and the highest net benefit, the two NOMEC Strategy scenarios that cost the least because they provide Order 2 data in the deeper waters rank highest.

Table 108. Offshore Bathymetry Benefit/Cost results

Quality Level	Update Frequency	Annual Total Benefits	Cost Per Year	Benefit/Cost Ratio	Net Benefits (Benefits/Costs)
Order 1a within 100 years with cost avoidance	100 years	$680,043,348	$70,357,406	9.67	$609,685,942
Combined Nearshore and Offshore NOMEC Strategy (QL2B Nearshore, Order 1a 10-100 m depth, Order 2 >100 m depth with UxS as force multiplier)	> 40m depth by 2030, 0-40m depth by 2040	$1,537,032,991	$377,348,557	4.07	$1,159,684,434
Combined Nearshore and Offshore NOMEC Strategy (QL2B Nearshore, Order 1a 10-100 m depth, Order 2 >100 m depth)	> 40m depth by 2030, 0-40m depth by 2040	$1,537,032,991	$394,250,555	3.9	$1,142,782,436
Combined Nearshore and Offshore NOMEC Strategy (QL2B Nearshore, Order 1a Offshore) with cost avoidance	> 40m depth by 2030, 0-40m depth by 2040	$2,206,225,641	$721,290,327	3.06	$1,484,935,314
Order 1a within 30 years with cost avoidance	30 years	$680,043,348	$234,524,685	2.9	$445,518,663
Combined Nearshore and Offshore NOMEC Strategy (QL2B Nearshore, Order 1a Offshore)	> 40m depth by 2030, 0-40m depth by 2040	$1,502,379,404	$721,290,327	2.08	$781,089,077
Order 1a within 100 years	100 years	$103,925,435	$70,357,406	1.48	$33,568,029
Order 1a with cost avoidance	>10 years	$680,043,348	$469,049,370	1.45	$210,993,978
Order 1a with cost avoidance	6-10 years	$1,125,952,499	$879,467,569	1.28	$246,484,930
Order 1a with cost avoidance	4-5 years	$1,857,357,704	$1,563,497,901	1.19	$293,859,803
Order 1a (NOMEC Strategy) with cost avoidance	> 40m depth by 2030, 10-40m depth by 2040	$813,600,712	$703,588,325	1.16	$110,012,387

Quality Level	Update Frequency	Annual Total Benefits	Cost Per Year	Benefit/Cost Ratio	Net Benefits (Benefits/Costs)
Order 1a with cost avoidance	2-3 years	$3,142,977,167	$2,814,296,223	1.12	$328,680,944
Order 1a with cost avoidance	Annual	$7,402,697,283	$7,035,740,559	1.05	$366,956,724
Order 1a within 30 years	30 years	$103,925,435	$234,524,685	0.44	($130,599,250)
Order 1a (fill Bathy Gap Analysis)	6-10 years	$66,749,420	$187,961,447	0.36	($121,212,027)
Order 1a 10-100m depth, Order 2 >100m depth	>10 years	$97,847,120	$425,989,378	0.23	($328,142,258)
Order 1a 10-100m depth, Order 2 >100m depth with UxS as force multiplier	>10 years	$97,847,120	$416,974,979	0.23	($319,127,859)
Order 1a	>10 years	$103,925,435	$469,049,370	0.22	($365,123,935)
Order 1a, no acquisition of Pacific territories	>10 years	$98,911,588	$460,366,015	0.21	($361,454,427)
Order 1a (NOMEC Strategy)	> 40m depth by 2030, 10-40 m depth by 2040	$109,754,475	$703,588,325	0.16	($593,833,850)
Order 1a 10-100 m depth, Order 2 >100 m depth with UxS as force multiplier	6-10 years	$114,217,488	$781,828,086	0.15	($667,610,598)
Order 1a	6-10 years	$120,295,801	$879,467,569	0.14	($759,171,767)
Order 1a 10-100 m depth, Order 2 >100 m depth	6-10 years	$114,217,488	$798,730,084	0.14	($684,512,596)
Order 1a, no acquisition of Pacific territories	6-10 years	$114,559,500	$863,186,278	0.13	($748,626,778)
Order 1a 10-100 m depth, Order 2 >100 m depth	4-5 years	$135,613,074	$1,419,964,598	0.1	($1,284,351,524)
Order 1a 10-100 m depth, Order 2 >100 m depth with UxS as force multiplier	4-5 years	$135,613,074	$1,389,916,600	0.1	($1,254,303,526)
Order 1a	4-5 years	$141,691,388	$1,563,497,901	0.09	($1,421,806,513)

Quality Level	Update Frequency	Annual Total Benefits	Cost Per Year	Benefit/Cost Ratio	Net Benefits (Benefits/Costs)
Order 1a, no acquisition of Pacific territories	4-5 years	$135,333,068	$1,534,553,383	0.09	($1,399,220,315)
Order 1a	2-3 years	$154,911,149	$2,814,296,223	0.06	($2,659,385,073)
Order 1a 10-100 m Depth, Order 2 >100 m depth	2-3 years	$148,832,835	$2,555,936,275	0.06	($2,407,103,440)
Order 1a 10-100 m depth, Order 2 >100 m depth with UxS as force multiplier	2-3 years	$148,832,835	$2,501,849,879	0.06	($2,353,017,044)
Order 1a, no acquisition of Pacific territories	2-3 years	$147,778,446	$2,762,196,089	0.05	($2,614,417,643)
Order 1a	Annual	$159,905,054	$7,035,740,559	0.02	($6,875,835,504)
Order 1a 10-100 m depth, Order 2 >100 m depth	Annual	$153,826,740	$6,389,840,689	0.02	($6,236,013,949)
Order 1a 10-100 m depth, Order 2 >100 m depth with UxS as force multiplier	Annual	$153,826,740	$6,254,624,701	0.02	($6,100,797,961)
Order 1a, no acquisition of Pacific territories	Annual	$151,960,363	$6,905,490,223	0.02	($6,753,529,860)

6. Technology Trends and Risk Considerations

In Appendix L, Dewberry evaluated the opportunities, challenges and risks to a nationwide enhanced elevation program from a variety of factors. This appendix provides an overview of the following technologies.

- Topographic lidar technologies, including Single Photon Lidar, Geiger-Mode Lidar, and Linear-Mode Lidar as well as the enabling technologies for direct georeferencing of lidar systems.
- Photogrammetric technologies, including stereo photogrammetry, SfM photogrammetry, and the enabling technologies for photogrammetric camera direct georeferencing.
- Synthetic Aperture Radar (SAR) technologies, including IfSAR or InSAR) and Satellite Differential InSAR (DInSAR) as well as the enabling technologies for aerial IfSAR direct georeferencing.

- Topobathymetric lidar technologies.
- Sonar technologies, including SBES, MBES, dual-head MBES, curved array multi-beam sonar, side scan sonar, interferometric sonar, as well as the motion sensing systems for multi-beam sonar bathymetry.
- Bathymetric sonar platforms, including crewed surface vessels, uncrewed surface vessels, and autonomous surface vessels.
- SDB.

In addition to describing the technologies, potential risks of each as well as advantages and disadvantages are laid out.

Table 109 summarizes the major advantages and disadvantages of topographic mapping technologies.

Table 109. Advantages and disadvantages of topographic mapping technologies

Technology	Advantages	Disadvantages
Single Photon and Geiger-Mode Lidar	High altitude, high pulse density. good for broad area mapping.	Does not map through clouds. Some accuracy issues in dense vegetation. Requires extensive ground control targets for calibration. Appropriate for broad area topographic mapping only.
Linear-Mode Lidar	Best bare-earth DTM technology. Can satisfy 5cm and 10cm accuracy classes with high point density.	Does not map through clouds. Costs more for narrow corridors with sharp turns.
Aerial Stereo Photogrammetry	Can satisfy 5cm and 10cm accuracy classes. Well-established processes by American Society for Photogrammetry and Remote Sensing (ASPRS).	Does not map through clouds. Difficulties penetrating vegetation. Requires extensive ground control points (GCP) for aerial triangulation (AT). Automated processes yield DSMs rather than DTMs.
SfM Photogrammetry	Inexpensive plane and consumer-grade camera. Easy-to-use by novices. Requires minimal GCPs for control of AT.	Without understanding underlying technology, easy to fall into traps and achieve inaccurate results. Difficulties penetrating vegetation. No ASPRS rigorous processes established.
Satellite Photogrammetry	Large pool of qualified data providers for commercial satellite imagery.	Requires cloud-free imagery. Difficulties penetrating vegetation. Automated processes yield DSMs rather than DTMs. Less accurate than airborne mapping technologies.
Aerial SAR (IfSAR)	Best technology for mapping through clouds, fog, haze. Now available with 50 cm accuracy class and 2 m resolution.	Small pool of qualified data providers. High mobilization costs. For broad area mapping only. Less accurate compared to lidar.
Satellite Differential InSAR	Best technology for mapping post glacial rebound and subsidence with free (Sentinel-1) imagery	Commercial SAR has higher resolution and accuracy but is expensive. Imagery is seldom archived as required for time-series evaluations.

Table 110 summarizes the major advantages and disadvantages of technologies for mapping bathymetry.

Table 110. Advantages and disadvantages/risks of bathymetric mapping technologies

Technology	Advantages	Disadvantages/Risks
Topobathymetric Lidar	When waters are clear, maps rivers and the intertidal zone including topographic and bathymetric surfaces.	Bathymetric mapping success is dependent on water clarity and limited by depth.
Single-Beam Echo Sounder	Not dependent on water clarity. Maps shallow water bathymetry.	Uses a single transducer to transmit/receive acoustic data, producing a narrow data swath.
Multi-Beam Echo Sounder	Not dependent on water clarity. Ideal for deeper water and high-resolution bathymetry.	Time consuming operations in shallower water environments.
Satellite Derived Bathymetry	This technology is useful for general mapping purposes only but does not produce a high quality/high accuracy product.	Bathymetric mapping success depends on water clarity when satellite imagery was acquired. Accuracies can vary significantly.

Dewberry's conclusions regarding the technologies and their associated risk factors outlined in Appendix L are summarized below.

General

- Technology trends show continued evolutionary improvements in topographic and topobathymetric lidar system technologies.
- As lidar technology continues to evolve, changing hardware and software trends will provide additional tools for data providers and professional users, and quick/simple 3D viewing options for non-professional users will continue to improve.
- Future improvements to lidar hardware and software are expected to result in lower costs for acquisition and processing of data and new potential benefits; elevation technologies will continue to improve.
- Multiple technologies will need to be employed for collection of elevation data, and the resulting datasets will need to be merged into a seamless surface for a product that can be used by professional and non-professional users.
- Although upcoming changes to the horizontal and vertical datums will impact all geospatial data, such datum changes should not hamper or delay data acquisitions. When the new geometric reference frame is implemented in the 2020's, new elevation data will be produced to the new datum and existing elevation data can be converted from the current North American Vertical Datum of 1988 (NAVD 88) to the new North American-Pacific Geopotential Datum of 2022 (NAPGD2022) vertical datum.

Photogrammetry

- The main risk of SfM photogrammetry is that the technology is so easy to use that results will always be provided by the software, regardless of the accuracy or inaccuracy of input parameters. Without understanding the underlying technology, it is easy for novices to fall into traps and claim accuracies that the data does not support. Currently, ASPRS has not established rigorous processes for SfM photogrammetry.

Synthetic Aperture Radar

- IfSAR data (satellite or airborne) lack the resolution and accuracy required to satisfy most Business Use requirements of the 3D Nation Study respondents.
- Satellite DInSAR offers potential for mapping changes in water surface elevations – something that airborne IfSAR cannot do well. DInSAR is also ideal for mapping annual rates of isostatic rebound and/or land subsidence.
- Commercial SAR has higher resolution and accuracy but is expensive. Imagery is seldom archived as required for time-series evaluations.

Topobathymetric lidar

- Topobathymetric lidar can provide the highest accuracy data to map rivers and streams as well as the entire intertidal zone. However, it is totally dependent on the turbidity, flow rate, bottom reflectivity, and absence of aquatic or subaquatic vegetation of the waters being mapped.
- For coastal mapping of nearshore bathymetry, topobathymetric lidar should first be acquired to determine how deep the area can be mapped with lidar, minimizing the use of the more expensive sonar to map out to deeper waters.
- Currently, topobathymetric lidar contractors fly to different standards and specifications when acquiring data for JALBTCX, the NOAA/NGS Remote Sensing Division, or the USGS National Geospatial Program. The Naval Oceanographic Office also uses different topobathymetric mapping criteria. These agencies are currently working to develop common specifications, with plans to release those specifications at the JALBTCX workshop in June 2022.

- The “white ribbon” closest to shore, that highly dynamic transitional zone between terrestrial and marine environments, is the most difficult to map. It is dangerous for boats; the wave action creates problems for lidar; and the water is often too murky due to suspended sand or silt for lidar, photogrammetry, or SDB. Integrating multiple elevation datasets acquired by a suite of remote-sensing technologies into a seamless digital dataset will likely be needed. It is often best to collect lidar at low tide and sonar at high tide. The use of uncrewed systems may also be advantageous in these areas.

Satellite Derived Bathymetry

- SDB is the least expensive and is largely dependent on water clarity and the quality of available satellite imagery.

- SDB is useful for general mapping purposes and acquisition planning, but does not produce a high quality/high accuracy product. It is totally dependent on water clarity and the quality of satellite imagery.

Sonar

- Sonar is excellent for mapping deeper waters regardless of water clarity and with or without vegetation, but sonar is limited in its ability to acquire data at depths shallower than the 3.5-meter NALL for safety of navigation. A large selection of MBES sensors are available commercially.

- Sonar’s main disadvantage is that it is very expensive in shallow waters, and it is also expensive in deeper waters when mounted on crewed survey vessels that are very costly to mobilize to a project area and costly to operate.

- Uncrewed Surface Vessels (USVs) have greatly increased productivity, enabling a single operator on a mothership, for example, to control multiple USVs collecting MBES data simultaneously. USVs can also be used effectively to collect bathymetry in lakes and rivers where conditions are unsuitable for topobathymetric lidar collection.

- Autonomous Surface Vessels (ASVs) have further increased productivity, operating over-the-horizon with or without a support vessel. Some can operate autonomously for several weeks to over a year without servicing. Power can be supplied by a mix of small diesel engines, solar, and wind energy. Large fleets of such ASVs are seen as the most cost-effective way to execute the NOMEC Strategy.

- With a large number of USVs and ASVs mapping the oceans and collecting huge amounts of data, there is expected to be a shortage of qualified data processing capacity in the U.S.

- Crowd-sourced bathymetry (CSB) is another source of data being evaluated. Bathymetry can be collected by non-research vessels, using standard navigation instruments that measure depths while engaged in routine maritime operations, whether fishing or transporting cargo. However, further research is needed to understand how accurate CSB data can be and how best to curate CSB data - assess its data quality and ingest, post-process, and grid it.

7. Program Management Lifecycle Considerations

When considering the costs to implement, enhance, or expand a national elevation program, in addition to the data acquisition costs that have been considered in the BCAs, the program will need to be supported by a robust infrastructure that provides program management and lifecycle data management support. This would include activities such as governance, outreach, contract oversight, data management (e.g., data inventory, data quality validation, data archive, etc.), data processing to prepare derivative products, data provisioning to make products available to the public in ways that support their needs, and research and development to identify and enhance technologies that can best serve a national elevation program. All of these activities will need to be supported by personnel and an Information technology (IT) infrastructure that includes hardware, software, networks, and commercial cloud resources, and an IT strategy that can process and deliver the volume of data resulting from a national elevation program.

Table 111 depicts some of the major elements of the lifecycle management of a national elevation program for which costs should be considered.

Table 111. Lifecycle cost elements of a national 3D elevation program

3D Nation Lifecycle Management Cost Elements
Program planning, outreach and governance including the development and maintenance of standards and specifications
Contract management, planning, and management of data acquisition partnerships among various federal, state, and local agencies
Data validation of all acquired data and products
3D Nation data research and development (e.g., remote sensing technologies, including airborne, spaceborne, uncrewed systems, etc.)
3D Nation data production, maintenance and management beyond what is contracted to private sector
3D Nation data/database management and delivery
IT systems support staff for 3D Nation data
IT systems for 3D Nation (servers and cloud)

Figure 33 depicts some of the major elements of program development that are needed to establish a national 3D elevation program.

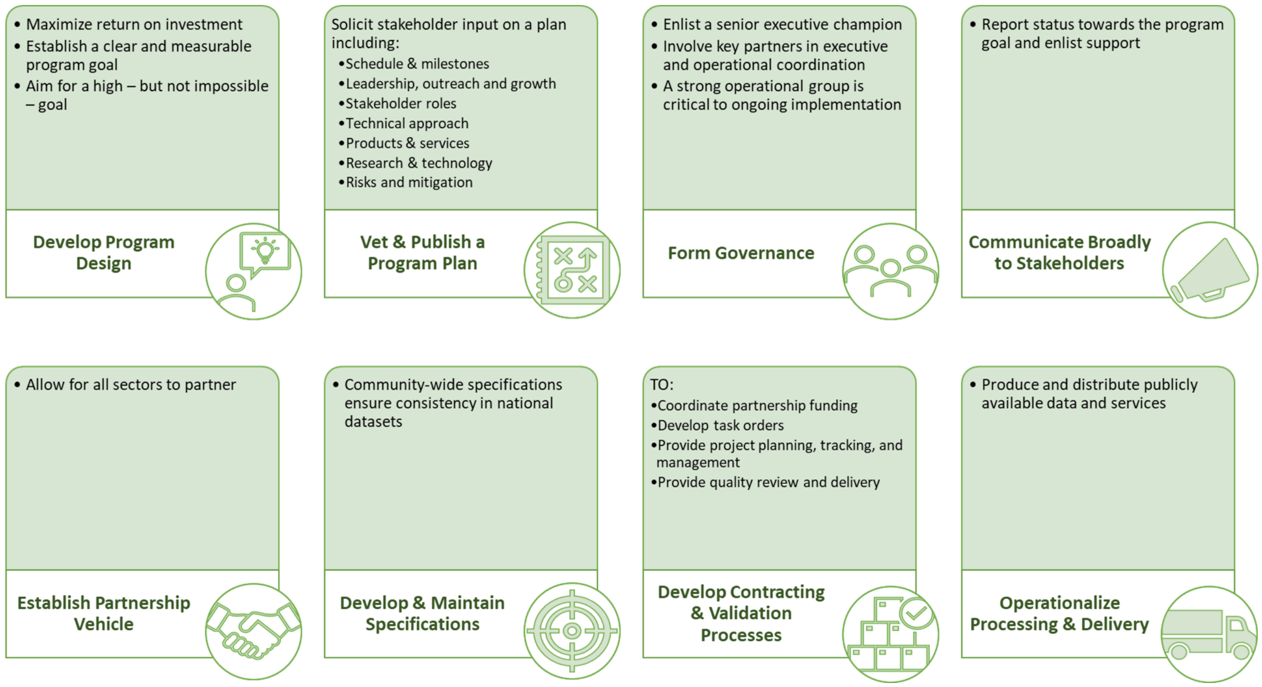


Figure 33. Major program development elements needed for a national 3D elevation program

Once the initial national elevation program is developed, an institutional program management framework is needed. The detailed program management components may vary in order and by agency, but the basic components include:

1. **Program Governance** – A strong governance framework is critical to ongoing implementation of a national elevation program.
    a. *Executive & Operational* - Key partners must be involved in the executive and operational coordination of a national elevation program. Interagency coordination is needed to establish and update the policies and procedures of a national elevation program.
    b. *Standards & Specifications* - Community-wide specifications ensure consistency in national datasets. As technologies change and programs evolve, standards and specifications must adapt, and the changes must be coordinated with the wider elevation community
2. **Outreach** – Continual outreach to partners and stakeholders is required to ensure a national elevation program continues to be responsive to the changing needs of users, to raise awareness of the program among agency geospatial leadership, and to promote best practices for interagency collaboration.

3. **Data Acquisition Coordination –** Coordinating the data-collection priorities of various stakeholders into annual acquisition planning is an ongoing task throughout the lifecycle of a national elevation program. Coordinating elevation data acquisition across stakeholders reduces the cost of acquisition through economies of scale, minimizes duplication of effort, and helps identify funding partners where agency priorities intersect. Individual data collection projects require coordination of funding partnerships, funding agreements, documentation of project requirements via task orders, and management of the contracts through the data acquisition and delivery process. Significant coordination with partners is required to ensure that the resulting data meet the needs of all.

4. **Processing and Delivery –** A vital element of a national elevation program is that the data and products are shared with the public. The Program must continually adapt its delivery mechanisms to satisfy changes in user requirements for data access, changes in technology, and the need for customized/non-standardized product generation needs. This continuous improvement of data processing capabilities and the data distribution methods must be coordinated with stakeholders as part of operational governance

5. **Research –** As technologies for collecting/processing and/or delivering elevation data change, a national elevation program must be able to assess the impact of such changes to the wider elevation community and the national elevation program itself. Research should include continuous improvement developments on operations, delivery and maximizing cost savings for producing and disseminating data

The technology and institutional framework will also need to be able to support the activities associated with collecting elevation data as acquisition occurs on an ongoing basis according to the program collection schedule. As these data are collected, they will need to be processed for inclusion in a national repository and served to users as the data become available.

When looking at the needs and potential future expansion requirements for provisioning nationwide elevation data to the public, the following entities currently serving elevation data were examined.

- USGS TNM
- NOAA Digital Coast
- NOAA NCEI
- NOAA OCS

Input on the infrastructure that supports each of these platforms was provided by USGS and NOAA as noted in Appendix M in sections on each of the individual platforms.

Based on the information provided by USGS and NOAA, it is evident that there is significant cost and management required for data storage and dissemination of high-resolution elevation data. The following observations regarding program and lifecycle management systems and costs are provided.

- Acquisition costs do not include program and data lifecycle management cost elements.
- USGS and NOAA each already have robust program management and information technology support systems in place. However, these will likely need to be expanded to support the additional data generated by an expanded national elevation program.
- Data volumes are only going to increase as data density (i.e., Quality Level) and geographic area covered increase (due to repeat collections). Therefore, system architecture and storage systems will likely need to be expanded to support the increased volume of data. Costs will thus also increase.
- User appetite for data will also increase as more data become available and more users appreciate its value. Therefore, data provisioning systems may need to be expanded or modernized further.
- Program management, acquisition planning and coordination, and contract management requirements will increase as an expanded national elevation program is implemented.
- A general rule of thumb is that QA/QC costs run about 10-15% of data acquisition costs. Lifecycle management costs (including QA/QC costs) are likely to be on the order of 20-25% of acquisition costs and are likely to increase somewhat as data volumes increase over the life of a program. (The 2012 USGS NEEA report estimated 6-10% for IT infrastructure costs, not including QA/QC of contracted data acquisitions; the recent USGS 3D National Topography Model Call for Action: 3D Hydrography Program draft report estimated 8.8% for lifecycle management costs, again not including QA/QC of contracted data acquisitions.)
- Continued and frequent coordination between USGS, USACE, NOAA, and other federal partners regarding elevation data needs and acquisitions will remain important to reduce the costs for mobilization and demobilization, minimize duplication of efforts, and identify funding partnerships.
- It is important for the federal government to continue research and development efforts of their own as well as and working with the private sector to identify and test new technologies that can reduce acquisition costs.

8. Observations and Conclusions

This section provides some high-level observations about the data that were collected during this study and the results of the analyses performed on the data. The observations cover the maturity of current acquisition systems and user familiarity with the resulting data, collaboration among federal agencies and their partners, risks associated with the elevation data collection technologies, and some of the reasons why we believe the benefits of elevation data were undercounted by the study respondents. Additionally, there are several steps that could be taken to fill what we perceive as gaps in future annual benefits estimates. These include additional individual outreach to known users of elevation data in underrepresented industries as well as mining previously conducted economic valuation studies to estimate the percent of various economic sectors or programs that rely on elevation data and their value.

8.1. Acquisition

The following observations are provided regarding the maturity of acquisition systems and programs as well as user familiarity with the use of elevation data to support their programs.

8.1.1. Inland Topography

- The 3DEP has almost completed its first pass of elevation data collection for the Nation with QL5 IfSAR in Alaska and QL2 lidar elsewhere in the U.S.

- The 3DEP data acquisition technologies, processes, and products are mature. IfSAR and lidar acquisition costs are well understood.

- Many users have developed robust systems for using lidar data and thus could estimate their future annual dollar benefits for enhanced elevation data. However, many other users still don't know what to do with the data to best serve their programs and could not estimate their benefits.

8.1.2. Inland Bathymetry

- There has been very little inland bathymetry collected and made publicly available to date. USGS has collected data for a few pilot projects and USACE has collected data in some navigable waters, but overall, very little data are available. 17% of the respondents said the data they need are not available; 26% report using navigation charts as the source of inland bathymetry rather than a DEM.

- While topobathymetric lidar collection technology and processes are well understood for coastal areas, they have not been tested in many of the challenging inland river or lake environments. The understanding of how well topobathymetric lidar will work in the varying conditions of water clarity, turbidity, and depth in the inland waters of the U.S. is not as advanced as it is for coastal areas. And there are many challenging areas where other conditions such as rapids, overhanging vegetation, steep banks, and inaccessible surrounding terrain could make sonar collections difficult and expensive, even using unmanned systems.

8.1.3. Nearshore Bathymetry

- NOAA, USACE (via the JALBTCX acquisition program), and USGS have been collecting nearshore bathymetric data for many years. Much of the nearshore areas of the U.S. have at least one collection of topobathymetric data available. However, the coastal zone by nature is a very changeable area due to storms, wave action, erosion and other natural and manmade impacts. In addition, the existing data may be of mixed Quality Levels and/or age. Additionally, the data may have been collected to slightly different specifications depending on which agency did the acquisition and for what use the data were intended.

- The topobathymetric lidar data acquisition technologies, processes, and products are mature and the acquisition costs are well understood. The topobathymetric sensors keep improving so data quality should continue to improve, and costs may continue to go down.

- Due to varying environmental conditions there will be unavoidable data voids where waters are not clear, in the "white ribbon" where the surf is high, etc. However, coordinating acquisition windows to tide levels and water clarity (i.e., using NOAA's Water Clarity Climatology K_d Viewer) can reduce the data voids.

8.1.4. Offshore Bathymetry

- NOAA has been acquiring hydrographic data for many years using MBES or SBES and supplemented with side scan sonar and backscatter. However, this zone is also very changeable, and the current pace of collection does not meet the Nation's needs.

- Private industry collects offshore bathymetry for its own needs as well (e.g., for oil and gas exploration or extraction, offshore wind farm siting, etc.) but typically do not share the data that are acquired. NOAA has entered into a pilot Memorandum of Agreement with Orsted (offshore wind energy) to explore a data sharing model and has also developed a data licensing policy to facilitate sharing. However, federal data specifications and delivery requirements may be a significant barrier to entry into such a program for some private entities. Data normalization between partners may also be an issue.

- Several private companies are focusing on developing UxSs for use as stand-alone collection systems or in tandem with a crewed vessel. It is expected that may boost acquisitions at significantly lower costs if the need for crewed vessels and their associated costs can be reduced or eliminated.

- Crowd-sourced bathymetry data whereby commercial or private vessels collect and submit bathymetry while traversing their normal day-to-day travel routes has some potential to fill out collection areas. However, the data normalization and QC requirements may be significant. Additionally, predicting where data will be collected for project planning is likely to be very difficult.

- SDB is useful for general mapping purposes only. The data have coarse resolution (typically 2 meters) compared with fine resolution (centimeters) from topobathymetric lidar and sonar; SDB is totally dependent on water clarity and the quality of the satellite imagery; SDB data are not SOLAS compliant; SDB data cannot be used where safety of maritime navigation is an issue; and there are no official IHO standards for SDB.

- Crewed hydrographic survey vessels have been the mainstay for collecting bathymetry for many decades. The main advantages are that traditional sonar mapping technologies and platforms are tried, proven, and reliable. The main disadvantage is the relative high cost of such surveys. Fortunately, innovative and lower-cost solutions are now available to execute the NOMEC Strategy.

8.2. Collaboration

The following observations are provided regarding the importance of collaboration to a national elevation program.

- Continued coordination between federal agencies regarding data acquisitions and funding partnerships is critical to reducing the possibility of duplication of effort as well as costs for mobilization and demobilization. Tools such as the U.S. Federal Mapping Coordination site, currently managed by NOAA, can be used for federal agencies and their partners to collaborate on mapping data acquisition.

- The 3DEP BAA proposal process has been successfully used by USGS to identify partners for topographic data collection projects. A similar process should be considered to identify partners for collection of elevation data in other geographies.

- Currently, topobathymetric lidar contractors fly to different standards and specifications when acquiring data for JALBTCX, the NOAA/NGS Remote Sensing Division, or the USGS National Geospatial Program. These agencies should continue to bring their differing specifications into alignment which should improve future interoperability across collection areas.

8.3. Technology Risks

Each of the technologies for collecting elevation data evaluated in Appendix L is subject to risks that may affect their ability to capture elevation data accurately. Most of these risks are associated with environmental conditions (e.g., clouds, fog, turbidity of water). Some can be overcome by careful planning of collection missions. Others may be beyond human control and may result in the need for repeat acquisition missions or acquisition with an alternate technology. The following are the major risks to technologies for elevation data acquisition.

- The major risk to all optical technologies is caused by clouds or fog which impact topographic and topobathymetric lidar, SfM, and SDB.

- Topobathymetric lidar technology risks include water depth, flow rate, turbidity, and bottom reflectivity. A hybrid approach for collecting inland bathymetry employing topobathymetric lidar for shallower and clearer areas, multi-beam sonar for deeper channels), and single-beam sonar using a UxS in areas that are too shallow for MBES and too turbid for lidar. To achieve a complete bottom surface model, the topographic lidar, topobathymetric lidar, and sonar data then need to be merged in order to fully satisfy objectives of the 3D Nation initiative.

- Turbidity is the single most important consideration for success of a topobathymetric lidar project. Local knowledge of turbidity and its drivers in the survey area is key to scheduling a topobathymetric lidar survey with the greatest chance of success. Turbidity can be highly variable depending on the day or the season. Similarly, water turbidity is the major risk to success of SDB.

- For safety purposes, MBES surveys are normally performed in waters deeper than the NALL; some systems are better than others for waters shallower than the NALL, but they too have risks that the platform could run aground.

- All Offshore Bathymetry cost estimates vary by depth of water. This is because MBES swath widths decrease as water depth decreases, therefore costs increase dramatically because the number of passes needed to collect full bottom coverage increases. Depth bands derived from the GEBCO 2020 grid were used to estimate average costs per SNM. The GEBCO grid is a global terrain model for ocean and land, providing elevation data, in meters, on a 15 arc-second interval grid compiled from multiple data sources.

  Any water areas where the gridded depths are underestimated will result in inflated cost estimates and therefore decreased BCRenefit/Cost results. This may be the case for the Great Lakes, based on an estimate of the cost to collect bathymetry for the Great Lakes prepared by the Great Lakes Observing System (GLOS)[7].

8.4. Undercounted Benefits

The following observations are provided regarding possible reasons why dollar benefits are underreported for this study.

- Federal agencies find it hard to estimate dollar benefits in general.

- Private industry is hesitant to reveal costs and business practices.

- Respondents were hesitant to estimate benefits from data they do not have access to or use regularly. 3DEP data are better known and understood than bathymetry. Many users have developed robust systems for using topographic and topobathymetric lidar data and thus could estimate their future annual dollar benefits for enhanced elevation data. However, other users still don't know what to do with the data to best serve their programs and could not estimate their benefits. Additionally, there is not much availability of inland bathymetry data yet and we believe many users could not envision how to use such data or what the benefits of having such data would be to their programs.

[7] https://glos.org/wp-content/uploads/2021/12/Costs-and-Approaches-for-Mapping-the-Great-Lakes.pdf

- Study participants from federal agencies were nominated by the agency POCs. The state participants were nominated by the state champions. Private industry participants were nominated by the USGS and NOAA study team and/or were invited as members of an association that represents an industry with a need for elevation data. Study participants may not have been as representative of the bathymetry community as the topography community due to prior experience with the NEEA topographic study.

- In our B/C model, dollar benefits are assigned only to the primary Business Use. The secondary and tertiary Business Uses do not get any dollar benefits assigned to them. Many respondents had a hard time choosing just one Business Use as primary; thus we believe many Business Uses are underrepresented.

- Of the 24,000+ private sector engineering firms and 16,000+ private sector land surveying firms in the U.S., only one small engineering firm responded to the 3D Nation questionnaire. That one engineering firm indicated millions of dollars in annual savings from the availability of accurate and authoritative elevation data in the public domain routinely used for engineering studies and engineering design services and topographic surveys mandated by local zoning and permitting regulations. NOAA and USGS had no way to contact 40,000 engineering and surveying companies to document their elevation data requirements and benefits, and it would have been impractical to do so; however, if many of the 24,000 other engineering firms and 16,000 land survey firms had similarly responded, the annual benefits of public domain elevation data would have been billions of dollars higher, spread across most of the 30 Business Uses.

- For maritime navigation and safety, there are many thousands of recreational boaters, commercial fishing vessels, oil tankers, cargo carriers, cruise ships, tugboats, etc. that rely upon inland, nearshore and offshore bathymetry for navigation purposes and to maintain under keel clearance while avoiding rocks, shoals and other obstacles. A single ship running aground incurs tremendous costs. America's seaports move trillion of dollars' worth of international cargo, relying on accurate bathymetric data for safety of navigation; however, the study team, including NOAA and USGS, was unable to identify any organization that could represent the diverse maritime industry and estimate the value of bathymetric data needed for maritime navigation and safety. Individual companies invited to the study were hesitant to state benefits or were nonresponsive. For this reason, benefits for inland, nearshore and offshore bathymetry are severely undercounted in this study.

- Other ocean industries such as oil and gas, wind energy, mineral extraction, etc. are also underrepresented in the study and those requirements and benefits are undercounted in this study.

- Many respondents were able to assign qualitative benefits (i.e., Major/Moderate/Minor) but were unable to assign a dollar benefit to the availability of elevation data. If we could assign a dollar benefit to "Major" benefits, the dollar benefits would increase significantly.

  For instance, if the hundreds of reported "Major" Operational and Customer Service benefits could be translated into a one percent savings of the total program budgets, this could easily be translated into tens of billions of additional dollars in annual savings. But we do not know the program budgets and have no way of knowing if a one percent savings is appropriate or not.

  We do know that for those that reported "Major" Operational benefits as well as dollar benefits, the value of "Major" benefits ranges from $1.2 to $8.2 million. If the average $4.5 million value of "Major" Operational benefits were applied to the 447 MCAs that reported "Major" Operational benefits but could not estimate any dollar benefits, the total estimated annual dollar benefits could increase by as much as $2 billion.

- We believe that data are missing for several Business Uses for which inland topographic data play a key role. This includes the following.

  BU 01 – Water Supply and Quality
  - States including CO and IL submitted MCAs for which BU 01 was secondary, and AR, IN, MD, NH, NY, and PR had no MCAs that listed BU 01 as either primary, secondary, or tertiary. Recognizing that water quality is a major issue in all of these areas, and especially for the Chesapeake Bay, Long Island Sound, Great Lakes, and Puerto Rico, we believe the BU 01 benefits are understated.

  BU 02 – Riverine Ecosystem Management
  - States including AR, CO, DC, FL, GA, HI, KS, MD, MI, MO, ND, NH, NY, OH, OK, PA, WI, WV, and PR did not include an MCA for BU 02 even though their major rivers include the Missouri, Ohio, Potomac, Hudson, Allegheny, Delaware, Susquehanna, Rio Grande, Platte, Colorado, St. Johns, and Red Rivers.
  - Only Trout Unlimited submitted an MCA with BU 02 as its primary Business Use. The Nature Conservancy and other non-governmental agencies did not identify BU 02 as primary, although riverine ecosystem management is known to be important to many non-governmental agencies.

  BU 03 – Coastal Zone Management
  - USACE and NRCS submitted MCAs listing BU 03 as secondary, and DISDI and NASA listed BU 03 as tertiary, meaning dollar benefits do not accrue to BU 03. The remaining federal agencies did not submit MCAs that designated BU 03 as either primary, secondary, or tertiary, including BLM, BOEM, FWS, USCG, USMC, and USN, all of which have significant coastal zone management missions.

- NY and NH did not provide any MCA with BU 03 as primary but would appear to have needs for elevation data for coastal zone management.

BU 04 – Forest Resources Management

- No commercial timber companies, either large or small, participated in the survey. The top ten timber companies in the U.S. include Weyerhaeuser, Georgia-Pacific LLC, West Fraser Timber Co. Ltd., Sierra Pacific Industries, Interfor Corporation; Hampton Affiliates, Inc.; Canfor; Idaho Forest Group, LLC, RSG Forest Products Inc., and PotlatchDeltic. Because these companies did not participate, benefits to them from public domain elevation data were not included.

BU 05 – Rangeland Management

- Rangeland management benefits to private landowners were not considered because NRCS's MCA listed BU 05 as tertiary.

BU 06 – Natural Resources Conservation

- ARS, FWS, and USFS submitted MCAs with BU 06 as secondary, and EPA submitted an MCA with BU 06 as tertiary; their financial benefits therefore do not accrue to BU 06. Many other federal organizations that manage land areas (e.g., DISDI, USACE, USMC, and USN) would seem to have a need to manage natural resources on their lands; but they did not submit an MCA listing BU 06 as either primary, secondary, or tertiary.

BU 07 – Wildlife and Habitat Management

- The USFS submitted an MCA that designated BU 07 as tertiary, meaning benefits did not accrue to BU 07.

- USACE is a strong advocate for wildlife and habitat management at its managed lake and river facilities, but USACE MCAs did not include BU 07 as either primary, secondary, or tertiary.

- DISDI, NRCS, USMC, and USN are all known to be strong supporters of wildlife and habitat management, but they did not include BU 07 as either primary, secondary, or tertiary on any of their MCAs.

- Trout Unlimited documented an MCA with BU 07 as secondary, and The Nature Conservancy documented an MCA with BU 07 as tertiary, meaning their benefits did not accrue to BU 07.

BU 08 – Agriculture and Precision Farming

- Many agricultural states (AR, CO, GA, KY, MA, MO, MS, ND, and SC) did not submit an MCA including BU 08 as either primary, secondary or tertiary.

- Only one non-governmental entity (Glorieta Geoscience) submitted an MCA with BU 08 as secondary. For the NEEA study in 2012, private sector precision agriculture (Precision Ag) firms were major contributors to the major cost benefits accrued to Agriculture and Precision Farming (contributing $122.3 million in benefits), but they did not participate in the 3D Nation study, so their input is totally lacking. This lack of input from private sector Precision Ag companies is the primary reason why benefits are seriously understated for BU 08.

BU 09 – Fisheries Management and Aquaculture

- FWS did not include an MCA with BU 09 as its primary Business Use. NOAA National Marine Fisheries Service listed only $180 thousand in benefits for Offshore Bathymetry and “Major” benefits for Nearshore Bathymetry.
- No benefits were reported for BU 09 from either LA or MS – two of the top aquaculture states in the U.S.
- Three non-governmental entities (Cooke Aquaculture, New England Fishery Management Council, and Taylor Shellfish Farms) submitted a total of three MCAs listing BU 09 as primary but only one provided dollar benefits for Nearshore Bathymetry; the other two listed “Major” benefits for Nearshore and Offshore Bathymetry. There are over 4,000 fish and seafood aquaculture businesses in the U.S.; only a small percentage of aquaculture firms participated in the 3D Nation Study.

BU 10 – Geologic Assessment and Hazard Mitigation

- No input was received from the Society for Mining, Metallurgy & Exploration Inc., the American Geological Institute, the Geological Society of America, or other national organization representing geologists; and nine states or territories with known geological programs did not submit MCAs listing BU 10 as primary, secondary or tertiary – meaning many geologists were underrepresented in this study.

BU 11 – Geologic Resource Mining and Extraction

- USACE did not submit any MCA that listed BU 11 as primary, secondary or tertiary even though USACE’s dredging and beach nourishment programs focus on the beneficial uses of materials dredged from navigable rivers.
- NOAA and BOEM reported “Major” benefits for Nearshore and Offshore Bathymetry but were not able to estimate dollar benefits.
- States such as AK, HI, MI, MN, and RI noted the importance of sand as a local resource, but most were only able to report “Moderate” benefits for Nearshore Bathymetry and “I don’t know” for Offshore Bathymetry.

BU 12 – Renewable Energy Resources

- BOEM, which manages the offshore lease program for wind lease blocks, reported "Major" benefits for Nearshore and Offshore Bathymetry but was not able to estimate dollar benefits.

- None of the East Coast states with offshore wind lease blocks were able to estimate either qualitative benefits or dollar benefits for Nearshore or Offshore Bathymetry, listing "I don't know" instead.

- Atlantic Shores Offshore Wind submitted an MCA with BU 12 as primary, providing $1 million benefits for Nearshore Bathymetry and $4 million for Offshore Bathymetry. However, the recent offshore wind lease sales of $4.37 billion indicate the dollar benefits to private industry may be considerably higher.

- No commercial onshore energy providers participated in the survey. For the NEEA study in 2012, NextEra Energy listed $10 million/year in benefits for wind farm siting. Because these companies did not participate, benefits to them from public domain elevation data were not included.

BU 13 – Oil and Gas Resources

- We believe the state dollar benefits are understated because major oil and gas producing states, including ND, LA, and OK did not submit MCAs with BU 13 as primary, even though they are among the top four states for oil or gas production in the U.S.

- One private firm submitted a well-documented MCA including dollar benefits for BU 13 for Nearshore Bathymetry. There are hundreds, perhaps thousands, of private sector oil and gas consulting firms in the U.S. that did not participate in the survey; if they had participated in similar way, the annual dollar benefits could be billions of dollars higher.

BU 14 – Cultural Resources Preservation and Management

- Research by archeologists in forested areas has found that: (1) topographic lidar can be effectively used, as a pre-field method, to detect cultural features such as mounds and pits in a forested environment; (2) topobathymetric lidar is also excellent in identification of underwater historical artifacts.

BU 15 – Flood Risk Management

- BIA, DHS, IJC, NASA, and USBR submitted MCAs listing BU 15 as secondary, and EPA and TVA submitted MCAs listing BU 15 as tertiary, meaning no benefits accrue to BU 15; and 24 federal agencies submitted no MCAs for BU 15 as primary, secondary, or tertiary.

- PA and PR submitted an MCA listing BU 15 as secondary, and MI submitted an MCA listing BU 15 as tertiary, meaning dollar benefits do not accrue to BU 15.

BU 16 – Sea Level Rise and Subsidence

- FEMA, USACE, USMC, and USN did not submit MCAs with BU 16 as either primary, secondary or tertiary; but each of these federal agencies will be severely impacted by sea level rise (SLR) and/or subsidence. For example, the world's largest naval base (Naval Station Norfolk) is subsiding significantly, compounding the already-serious impacts of SLR.

- SC submitted an MCA with BU 16 as secondary, even though SC is high on the list of states vulnerable to SLR. Similarly, LA and MS submitted MCAs with BU 16 as tertiary, even though both states are highly vulnerable to SLR and subsidence. No benefits accrued for MCAs listing BU 16 as secondary or tertiary.

- There were no MCAs submitted by non-governmental agencies listing BU 16 as primary, secondary, or tertiary.

BU 17 – Wildfire Management, Planning, and Response

- Members of the National Interagency Fire Center were expected to submit MCAs specifying BU 17 as primary, secondary or tertiary, but no such MCAs were obtained from DHS, BIA, BLM, or FWS.

- While many of the states hit hardest by wildfires in the past few years did submit MCAs that listed BU 17 as primary (including AK, AZ, CA, ID, MT, NM, OR, TX, UT, WA, and WY), CO listed BU 17 as secondary, even though it has experienced many significant wildfires in recent years.

BU 18 – Homeland Security, Law Enforcement, Disaster Response, and Emergency Management

- Two states submitted MCAs with BU 18 as secondary, and four states submitted MCAs with BU 18 as tertiary; these do not accrue any benefits to BU 18. Twelve states and territories did not list any MCAs with BU 18 as primary, secondary, or tertiary.

BU 19 – Land Navigation and Safety

- The FHWA submitted an MCA listing BU 19 as secondary, meaning no benefits accrued to BU 19.

- Twenty-two states and territories did not include an MCA with BU 19 as primary even though lidar data are widely used nationwide for land navigation and safety.

- General Motors reported $12.9 million in benefits for Inland Topography and HERE Technologies indicated “Major” benefits. However, TomTom did not submit an MCA for the 3D Nation Study, although TomTom previously submitted an MCA with the highest potential benefits of $6.129 billion for the NEEA study, based on its estimates of fuel savings from the use of DEMs for automated transmission control and predictive shifting as vehicles approached changing gradients and curves ahead.

BU 20 – Marine and Riverine Navigation and Safety

- USCG, USMC, USN, and USARC did not include an MCA with BU 20 as its primary Business Use.
- Eleven states and territories with ports did not submit MCAs with BU 20 as primary, including AL, GA, HI, MD, MS, NH, NY, OR, WI, PR, and AS though we assume navigation safety is important for each of them; this means their requirements and benefits were not counted.
- AAPA, Leidos, Lake Carriers’ Association, Geodynamics, QPS, ESGPlus, and U.S. Power Squadron listed MCAs with BU 20 as primary but were unable to quantify dollar benefits.

BU 21 – Aviation Navigation and Safety

- Four states submitted MCAs with BU 21 as secondary, and four states submitted MCAs with BU 21 as tertiary; these do not accrue any benefits to BU 21. Twenty-two states and territories did not list any MCAs with BU 21 as primary, secondary, or tertiary. However, all states and territories except perhaps D.C. could be assumed to have a need for aviation safety associated with airports under their jurisdiction.

BU 22 – Infrastructure and Construction Management

- Nine states and territories submitted no MCA with BU 22 as primary, even though infrastructure and construction management is known to be critical everywhere; five states submitted MCAs with BU 22 as secondary or tertiary.
- Eight NGOs submitted MCAs listing BU 22 as secondary or tertiary, meaning benefits do not accrue to BU 22.
- Very few engineering or surveying firms responded to the 3D Nation questionnaire, indicating significant annual savings from the availability of accurate and authoritative elevation data in the public domain routinely used for engineering studies and engineering design services, surveying and mapping, negating their company’s need for costly field surveys to obtain topographic and bathymetric data required for construction planning.

BU 23 – Urban and Regional Planning

- Whether called 3D virtual models, "digital twins" or other terms, high-fidelity replicas of the built and the natural environment, including trees and buildings, are instrumental in supporting urban and regional planners in one way or another.
- Of the 45 federal agencies participating in the study, only five federal agencies (DISDI, FBI, SI, TVA, USCB) submitted a total of six MCAs listing BU 23 as their primary BU.
- Nine states or territories submitted MCAs listing BU 23 as secondary or tertiary, meaning no benefits accrued to BU 23; two states and one territory did not include an MCA with BU 23 as either primary, secondary, or tertiary.

BU 24 – Health and Human Services

- Only 10 states and territories submitted MCAs listing BU 24 as primary. Two states submitted MCAs with BU 18 as secondary, and three states submitted MCAs with BU 24 as tertiary; these do not accrue any benefits to BU 24. Forty-one states and territories did not list any MCAs with BU 24 as primary, secondary, or tertiary.
- No NGOs submitted an MCA listing BU 24 as primary, secondary, or tertiary.

BU 25 – Real Estate, Banking, Mortgage, and Insurance

- There were no federal MCAs for BU 25. Two federal agencies submitted MCAs listing BU 25 as tertiary.
- Fifteen states and territories submitted MCAs listing BU 25 as their primary Business Use. Two states submitted MCAs listing BU 25 as secondary and one state submitted an MCA listing BU 25 as tertiary, meaning no benefits accrue to BU 25.
- There were no non-governmental MCAs listing BU 25 as primary, but one submitted an MCA listing BU 25 as secondary.
- There was no representation from the real estate, banking, mortgage, or insurance industries to the 3D Nation Study. However, for the real estate, banking, mortgage, and insurance industries to properly serve American homeowners, all must recognize risks from natural disasters, and many of those risks depend on the geographic location and/or topography of the terrain on which homes are built. Natural disasters are not the only reason why elevation data are critical for this Business Use. Daily, in every county in America, lands are purchased for which American Land Title Association surveys are required to establish legal boundaries. However, if the owner decides to build something on that property or get the property zoned for an intended use, topographic maps must be provided so city or county officials can issue building or zoning permits.

BU 26 – Education K12 and Beyond, Basic Research

- Only one federal agency, SI,) submitted an MCA listing BU 26 as their primary Business Use, whereas MARAD and NASA submitted MCAs listing BU 26 as secondary and tertiary. SI submitted only a total of $6,927 in benefits for Inland Topography, Inland Bathymetry, Nearshore Bathymetry and Offshore Bathymetry.
- Seven universities (Brown University, North Carolina State University, Oklahoma State University, Oregon State University, Pennsylvania State University, University of Maine, and University of Missouri) submitted MCAs listing BU 26 as primary; and Esri and Old Dominion University submitted MCAs listing BU 26 as secondary. However, a total of 82 academic institutions participated in the study, but only 25 listed BU 26 as their primary Business Use.

BU 27 – Recreation

- No MCA was received from the Recreational Boating community, a huge community of users that rely on inland bathymetry, nearshore bathymetry, and offshore bathymetry for safety of navigation.
- Only NPS submitted an MCA listing BU 27 as its primary Business Use, providing dollar benefits for Inland Topography and Inland Bathymetry and indicating "Major" benefits for Nearshore Bathymetry.
- With thousands of recreation areas at over 450 lakes and waterways, USACE provides fishing, boating, hiking and camping opportunities in 43 states, but USACE did not submit an MCA listing BU 27 as either primary, secondary, or tertiary, even though topographic and bathymetric data are vital for design and operation of these facilities.
- NOAA, TVA, USFS, and USGS all submitted MCAs listing BU 27 as tertiary, meaning no benefits accrued to this Business Use.

BU 28 – Telecommunications

- Elevation data are needed to determine line-of-sight conditions between transmit and receive locations for broadcast, microwave, cellular, WiFi, and other users. Digital Surface Models are used as inputs to automated propagation prediction software and to determine where the vegetated terrain and buildings could interfere with wireless telecommunications. Bathymetry is also critical to the siting of undersea cables.
- None of the 30 study participants that listed BU 28 as primary was able to provide dollar benefits. This includes DHS, FBI, FCC, and U.S. Air Force; twenty-three (23) states and territories; and three NGOs (HERE Technologies, Maxar Technologies, and SubCom).

BU 29 – Military

- Four federal agencies (DISDI, USACE, USAF, and USMC) submitted MCAs listing BU 29 as their primary Business Use, providing dollar benefits for Inland Topography only. No dollar benefits were provided for Inland Bathymetry, Nearshore Bathymetry, or Offshore Bathymetry, even though all of these agencies have management responsibilities both on land and water.

- DTRA, FBI, and NGA submitted MCAs listing BU 29 as secondary; and CMTS and USCG submitted MCAs listing BU 29 as tertiary meaning no benefits accrue to BU 29.

- Seven states submitted MCAs listing BU 29 as their primary Business Use but most listed benefits as “unknown.”

- One non-governmental organization (GSI Service Group, Inc.) submitted an MCA listing BU 29 as primary and providing dollar benefits. Leidos, a major defense and government services provider, submitted no MCA listing BU 30 as its primary Business Use. None of the other major DoD contractors participated in the study, even though elevation data are critical to their missions.

BU 30 – Maritime and Land Boundary Management

- Many boundaries are highly dependent on elevation data. NOAA is responsible for delineating the official shoreline of the U.S. Tidal datums are used to define the boundary between privately-owned and state-owned lands and to define inland waters, state submerged lands, territorial seas, contiguous zone, exclusive economic zone, federal submerged lands, and the high seas. BOEM manages development of U.S. Outer Continental Shelf energy and mineral resources. On land, BLM is responsible for the surveys of public lands only. Individual states are responsible for surveys on private lands. Too numerous to itemize, many state boundaries are defined by water boundaries.

- NOAA submitted an MCA listing BU 30 as secondary, and BOEM’s MCA on geologic resources mining and extraction did not include BU 30 as either primary, secondary, or tertiary – meaning no dollar benefits accrued from either federal agency seen as champions for this Business Use.

- Twenty-five states and territories submitted MCAs that designated BU 30 as their primary BU. Four states submitted MCAs with BU 30 as secondary, and one state submitted an MCA with BU 30 as tertiary; these do not accrue any benefits to BU 30. Twenty-six states and territories did not list any MCAs with BU 30 as primary, secondary, or tertiary.

8.6. What Else Could be Done?

8.6.1. Additional Outreach to Targeted Individuals or Industries

Individual outreach could be conducted with targeted private sector representatives to gather additional potential unreported or underreported benefits. Industries that are potentially underrepresented include the following:

- Commercial timber
- Precision agriculture
- Fish and seafood aquaculture
- Mining
- Wind energy
- Oil and gas
- Motor vehicle manufacturers
- Shipping, boating, fishing, and cruise lines
- Port and harbor managers
- Engineering and surveying
- Real estate, banking, mortgage, and insurance
- Telecommunications
- DoD contractors

8.5.2. Mine Previously Conducted Economic Valuation Studies and Estimating Tools

NOAA has previously conducted numerous valuation studies that could be mined for additional information. This effort could potentially estimate the percent of various economic sectors or programs that rely on elevation data and their value. However, to do this we would need input on the contributions of elevation data to the various sectors or programs. Not all sector or program dollar values can be ascribed to the availability of nationwide digital elevation data. The following prior reports may be of interest.

In addition to previously conducted economic valuation studies, NOAA has developed tools to help coastal managers and others estimate the value of the blue economy as well as intangibles such as ecosystem services. Such tools could be used to help estimate the total value of sectors or programs. We would still need to estimate the contribution of elevation data to the values. These tools include the following.

- Economics: ENOW Explorer which streamlines the task of obtaining and comparing economic data, both county and state, for the six sectors dependent on the ocean and Great Lakes: living resources, marine construction, marine transportation, offshore mineral resources, ship and boat building, and tourism and recreation.

- Coastal County Snapshots which provides a way to better understand county resilience in terms of flood hazards, critical facilities, jobs, businesses, and more. Current snapshot topics include flood exposure, marine economy, total economy, and exposure to sea level rise.

- Quick Report Tool for Socioeconomic Data which provides access to economic and demographic data for multiple coastal jurisdictions.

NOAA Report on the U.S. Marine Economy, NOAA Office for Coastal Management, 2021[8]

This report summarizes the benefits derived from the oceans and Great Lakes that result in jobs and wages that contribute directly to the gross domestic product (GDP). Six economic sectors are represented:

- Living resources
- Marine construction
- Marine transportation
- Offshore mineral extraction
- Ship and boat building
- Tourism and recreation

NOAA's estimate of the U.S. marine economy as of 2017 is $132 billion in wages, and $307 billion in GDP. Could we make some assumptions about how much elevation data contributes to these economic sectors?

Use and Value of Nautical Charts and Nautical Chart Data in the U.S., 2007, Hauke Kite-Powell for NOAA Office of Coast Survey[9]

This study is based on a survey of commercial and recreational boaters on their use of nautical charts, both paper and digital and a willingness to pay valuation methodology for "ideal" charts. The annual willingness to pay estimate for recreational boaters is $45.78/boat or $21.8 million in aggregate. For commercial vessels the average is $2,600/per vessel per year. An estimated 10,000 ships and tug/towboats operate in U.S. waters and 90% indicated use of digital charts. The commercial aggregate would be $23.4 million, and the total aggregate would be $45.2 million per year.

We know that accurate nautical charts depend on good elevation data. Can we make some estimates of what portion of nautical chart production depends on elevation data?

The Ocean Enterprise Study 2015-2020: **A study of U.S. New Blue Economy business activity,** NOAA 2021[10]

This study was based on a web-based survey and secondary research that extended to a total of 814 Ocean Enterprise businesses about their revenue and employment. Additional questions were asked

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[8] https://coast.noaa.gov/data/digitalcoast/pdf/econ-report.pdf
[9] https://www.worldcat.org/title/use-and-value-of-nautical-charts-and-nautical-chart-data-in-the-united-states/oclc/607302809

[10] https://ioos.noaa.gov/project/ocean-enterprise-study/

about using ocean observation data. 52% of respondents indicated they use bathymetric or hydrographic data products.

The study characterized business activity within this sector in order to understand the scope and scale of business activity supporting public missions and private sector growth within the overall economy. The Ocean Enterprise Study did not uncover any major surprises, but there were many interesting findings including the locations, size, and functions of firms in this sector, including:

- The study identified 814 Ocean Enterprise businesses.
- The Ocean Enterprise generated $8 billion in revenue annually.
- 75% of businesses have been operating 10 or more years in the Ocean Enterprise. More than 40% of them expect growth in their Ocean Enterprise business in the next year.
- Use of bathymetric or hydrographic data products increased from 34% to 52% between 2015 and 2020.

Is there a way to make assumptions about how the 52% who use bathymetry contribute to the $8 billion in annual revenues?

Projected Benefits and Costs of the Digital Coast, April 2015, NOAA Office for Coastal Management[11]

Annual net benefits are estimated at $2.3 million in 2009, $6.7 million in 2013, and estimated to be $117 million by 2028. Benefits were calculated by comparing costs to provision data vs. the cost users would expend to obtain the data without Digital Coast. Intangible benefits also come from preservation of communities and natural resources as a result of having the data available.

Can we get numbers for elevation data only or an estimate of the percent of Digital Coast that represents elevation data?

NOAA by the Numbers: NOAA's Value to the Nation, 2018[12]

NOAA contributes value to the economy in two fundamental ways. First, by providing information that people find valuable and that people use to guide or influence decisions, and second, by managing, or helping to manage, natural resources that are themselves valuable. Understanding the economic worth created by NOAA involves asking how people use/value the information that NOAA provides, or how the values of resources are enhanced through NOAA management.

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[11] https://coast.noaa.gov/data/digitalcoast/pdf/benefits-costs.pdf

[12] https://www.noaa.gov/sites/default/files/legacy/document/2019/Nov/NOAA-by-the-Numbers-Accessible-Version-Corrected-17-JUL-18%20%281%29.pdf

Information that NOAA provides is placed into two general classes: (1) operational information; and (2) research information. Both kinds of information derive their value from the ways people use the information, but there are significant differences in the challenges in estimating their values.

Each day, nearly every American relies on the data, products, and services NOAA provides. These products and services include daily weather forecasts, navigational tools to support the country's nearly $4.6 trillion in economic activity generated by U.S. seaports, assessments on the health of the nation's $200 billion fisheries, and disaster response. For example, Lazo et al. (2011), found that GDP varies 3.4 percent from year to year due to weather; this equated to $485 billion per year in 2008 (the figures cited in the study) or $545 billion in 2016. Variability can be positive or negative.

Businesses that are directly dependent on the oceans and Great Lakes resources contribute more than $350 billion to the nation's GDP, supporting more employment than crop production, telecommunications, and building construction combined.

In 2015 alone, 1.39 billion short tons account for $1.56 trillion worth of U.S. goods that moved through U.S. ports. Imports and exports via water represented 71 percent of U.S. imports and exports by weight and almost 42 percent of cargo value in 2015.

Coastal Ocean Observations & Related Products

- In 2014, U.S. seaports moved $1.46 trillion of goods in international cargo, supporting agriculture, manufacturing, retail trade and other activities with a total economic impact to the national economy that exceeds $4 trillion annually.
- More than 400,000 workers are directly employed in the marine transportation sector but more than 20 million jobs, in sectors ranging from agriculture to manufacturing and retail trade, depend on the access to international markets provided by seaports.
- As intermodal hubs for international trade, seaports are also vitally important to the $822 billion railroad and motor carrier transportation industries. NOAA facilitates the shipping industry by producing accurate surveys and charts, which will become more important as the volume of traffic, and value of exports and imports in U.S. seaports is expected to double by 2021, and double again shortly after 2030.
- The NOAA Physical Oceanographic Real-Time System® (PORTS) is a collection of oceanographic and meteorological instruments integrated into a system to provide accurate, reliable, real-time, quality-controlled information about the environment in which mariners and recreational personnel operate. The annual benefit from reduced vessel transits resulting from maximized use of channel depth, reduction in vessel transit delays, enhanced oil pollution remediation efforts, reduced commercial and recreational marine accidents (collisions, allisions, and groundings) as well as enhanced fishing was estimated to reach

$300 million in 2010 ($330 million in 2016), if PORTS was implemented at the top 175 busiest seaports.

- Volpe (2008) suggested that nautical charting and PORTS contributed a combined annual benefit of $1.2 billion ($1.4 billion in 2016) to the nation resulted from voyage planning, reduced vessel delays, optimal use of port capacity, averted groundings, diminished pollution releases, lessened morbidity and mortality.
- The NOAA-managed National Spatial Reference System (NSRS) "improves the quality of coastal and ocean observations by providing precise measurements of latitude, longitude, and elevation." The estimated benefit of these measurements is $2.4 billion ($2.7 billion in 2016) per year.
- The estimated economic benefit of the NOAA Continuously Operating Reference Stations network (which is part of NSRS and provides data to support 3D positioning, meteorology, space weather and geophysical applications) is $758 million per year based on the estimate of study conducted in 2009 ($844 million in 2016).
- NOAA's Coastal Mapping Program is responsible for NOAA's shoreline mapping activities, which provide critical baseline data for accurately mapping the nation's official shoreline, georeferenced disaster response imagery, and geographical reference data needed to manage, develop, conserve, and protect coastal resources. Total economic benefits from the CMP are estimated to be $241 million. Direct benefits of the program are 15 times the actual program cost and indirect benefits are 30 times the cost of the program. At the time of this study, the CMP was estimated to support 1,500 jobs.

Can any of these benefits be applied to NOAA's MCAs?

INFOMAR Marine Mapping Study Options Appraisal Report: Final Report 30 June 2008 PricewaterhouseCoopers[13]

The Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR) program is Ireland's national marine mapping program. It is the successor to the Irish National Seabed Survey and is a joint venture of the Geological Survey of Ireland and the Marine Institute. PricewaterhouseCoopers were commissioned by the Department of Communications, Energy and National Resources to undertake a detailed appraisal of the INFOMAR project.

This study identified direct and indirect benefits. For the indirect benefits analysis, benefits that could be linked to the INFOMAR data were identified, the financial value of the economic sector that

[13] https://oar.marine.ie/handle/10793/1652?show=full

would benefit from the data was estimated, the impact of the data on the sector was estimated with a range of scenarios, and a time frame for the accrual of benefits was estimated.

Could a similar exercise be undertaken by Business Use or business sector? Finding estimates of industry sector contributions to the GDP might be difficult for some industries. The NOAA Ocean Reports and ENOW Explorer tools have estimates for the marine economy. Other sources would likely need to be consulted for a broader range of Business Uses. A credible methodology for estimating the contribution of elevation data to each industry would also need to be developed and vetted.